Metal Casting

Annual Report 2000

May 2001

Metal Casting Industry of the Future
Office of Industrial Technologies
Energy Efficiency and Renewable Energy
U.S. Department of Energy

CONTENTS

Exhibits

GET INVOLVED!

Improve energy efficiency and productivity by applying the results of Metal Casting Industry of the Future research.

- *Visit the Metal Casting Team web site to learn more about Metal Casting Industry of the Future research accomplishments and partnerships: www.oit.doe.gov/metalcast*
- *Team with other organizations and participate in cost-shared research. Solicitations are published at www.oit.doe.gov/news/solicitations.shtml*
- *Begin saving energy through technical assistance from BestPractices or the Industrial Assessment Centers program: www.oit.doe.gov/bestpractices*
- *Contact the OIT Clearinghouse at (800) 862-2086 and take advantage of OIT's other technical information resources designed to help you save energy.*

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Each year, the Metal Casting Industry of the Future publishes an Annual Report to review its research portfolio and accomplishments for the year and to provide background information on the program. The Annual Report is prepared by ***BCS, Incorporated, Columbia, MD.***

INTRODUCTION

The Department of Energy's (DOE) Office of Industrial Technologies (OIT), Metal Casting Industry of the Future Program cost-shares vital research to improve energy efficiency and productivity in the U.S. metal casting industry. The Program emphasizes University-based research, addressing the vital national need to introduce students to our base industries. The metal casting industry is diverse and is comprised largely of small businesses. The IOF strategy has proven vital in leveraging academic and industry resources and in bringing industry together to address important crosscutting research needs. Industry is beginning to apply the results of this research. They are saving energy and improving competitiveness for U.S. metal casters. Some of these success include:

- extending die life by up to 50%
- reducing scrap and increasing yield in steel foundries
- introducing hundreds of students to the field of metal casting

The remainder of this report summarizes highlights and major accomplishments of the program during 2000.

The Metal Casting Industry of the Future, is coordinated through the Cast Metals Coalition (CMC). Collectively, this coalition represents the majority of the U.S. metal casting industry. The CMC is composed of:

- American Foundry Society (AFS)
- North American Die Casting Association (NADCA)
- Steel Founders' Society of America (SFSA)

Metal Casting Research Partnership

The success of the Metal Casting Industry of the Future is the result of a highly effective partnership between OIT and the U.S. metal casting industry. The Industries of the Future (IOF) strategy fosters government-industry partnerships in economically vital, energy intensive U.S. industries, including metal casting. Through the IOF strategy, OIT encourages each of the most energy-intensive industries to develop a Vision of their long-term future as well as Roadmaps, research and development (R&D) pathways to achieve that Vision. The Vision and Roadmap form the basis for open and competitive solicitations requesting pre-competitive R&D which addresses both national energy efficiency goals and industry needs for competitiveness and productivity.

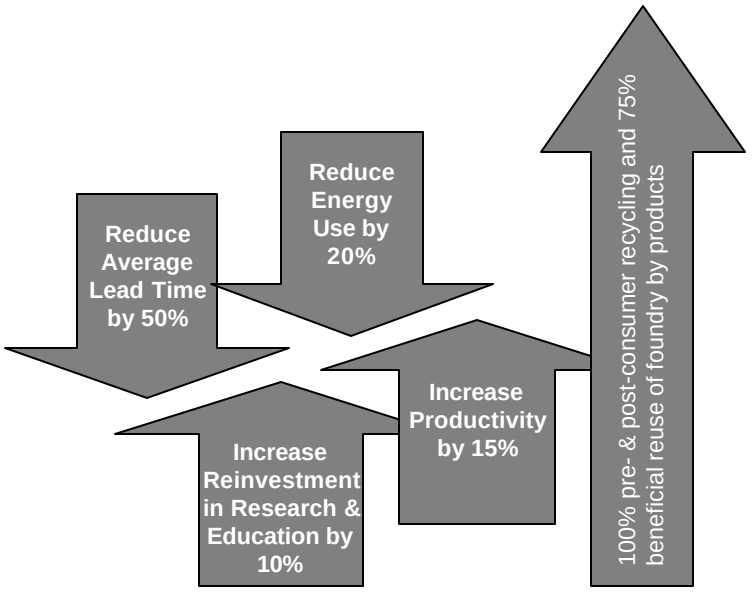
Emphasizing University-based Research

Metal Casting Industry of the Future Research is addressing one of industries most pressing needs – attracting a sufficient and well-trained workforce. The program partners with over 20 universities nationwide, training hundreds of students in the latest advances in metal casting. When these students take careers in metal casting, they bring the latest in technical knowledge and process advances to the shop floor. Metal Casting IOF alumni are now working in many sectors of the metal casting industry.

The metal casting industry developed a Vision, *Beyond 2000: A Vision for the American Metal Casting Industry*, followed by the Metal Casting Industry Technology Roadmap to guide research efforts. Exhibit 1 shows the goals identified by industry in the Vision. Additional information on the Vision, the Roadmap and the solicitation process is provided in Appendix A. The Metal Casting Industry of the Future builds upon the foundation put in place by the Department of Energy Metal Casting Competitiveness Research Act of 1990 (P.L. 101-425). It fosters collaborations between universities, national laboratories, and industry.

All metal casting research has broad application and is cost-shared with industry, leveraging millions of dollars in industry R&D funding. The Metal Casting Industry of the Future emphasizes university-based research thereby exposing hundreds of students to the field of metal casting and addressing industry's most pressing need -- to attract a sufficient and well-trained workforce.

Exhibit 1
Metal Casting Vision Goals



In 1995, the metal casting industry published *Beyond 2000: A Vision for the American Metalcasting Industry*. It outlines specific goals for the industry over the next 20 years. In 1998, the Metal Casting Industry Technology Roadmap was published. The Roadmap outlines research pathways needed to achieve Vision goals. It forms the basis for cost-shared research performed through the Metal Casting Industry of the Future.

Industries of the Future: A Successful Approach to R&D Partnerships

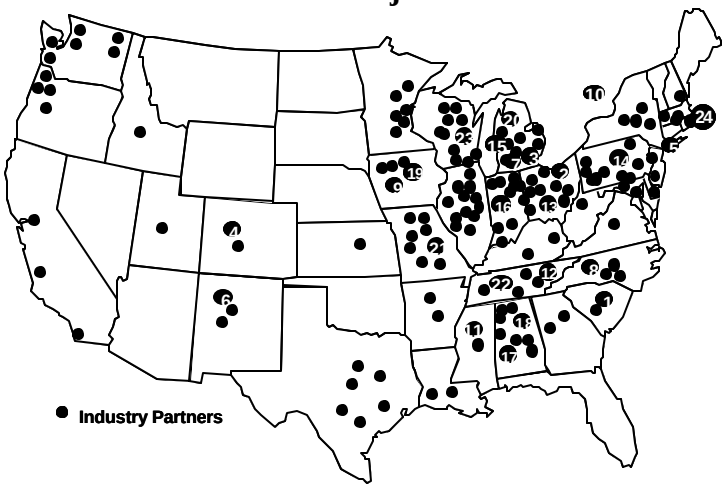
The involvement of industry on the ground floor helps to speed the pace of technology transfer and the dissemination of research results. By the end of 2000, program partners included 320 organizations from industry, universities and laboratories in 35 states (See Exhibit 2). Industry and university partners and their locations are listed by state in Appendix B.

Industry partners represent the diversity of the metal casting industry including suppliers, end-users, designers, ferrous and non-ferrous foundries, die casters and others. Together, they employ the range of metal casting techniques and supply to a broad range of end-use markets. This broad and diverse participation contributes to direct application of research results in industry. It also is evidence of the industry-wide importance of program-funded research.

Exhibit 2
Metal Casting Research Performers and Project Partners

Primary Research Performers

1. Advanced Technology Institute
2. Case Western Reserve University
3. Climax Research Services
4. Colorado School of Mines
5. Copper Development Assoc., Inc.
6. Arena, LLC
7. Hayes Lemmerz
8. Intl. Lead Zinc Research Organization
9. Iowa State University
10. Materials Technology Laboratory
11. Mississippi State University
12. Oak Ridge National Laboratory
13. Ohio State University
14. Pennsylvania State University
15. Prince Machine Corporation
16. Tri-State University
17. University of Alabama
18. University of Alabama - Birmingham
19. University of Iowa
20. University of Michigan
21. University of Missouri - Rolla
22. University of Tennessee
23. University of Wisconsin - Milwaukee
24. Worcester Polytechnic Institute



The Metal Casting Industry of the Future is partnering with 320 university, industry, and laboratory partners in 35 states across the U.S.

This approach to private-public partnerships ensures the strategic allocation of limited resources for the development of new technologies and the enhancement of metal casting processes. It is through this partnership that results are tested, disseminated and applied throughout the industry.

Addressing Energy Efficiency Goals

As stated in the Office of Industrial Technologies Strategic Plan, major goals of the U.S. Department of Energy and the Office of Industrial Technologies are: *"a 25 percent improvement in energy efficiency and 30 percent reduction in emissions for the vision industries by 2010"* and *"a 35 percent improvement in energy efficiency and 50 percent reduction in emissions for the vision industries by 2020."* The Strategic Plan states that "OIT will motivate and will assist industry to develop technology solutions to critical energy and environmental challenges... ."

Metal casting was selected as an Industry of the Future because it is one of the most energy-intensive U.S. industries. The U.S. metal casting industry consumes an estimated 200 trillion Btu per year.[1] This does not include the many captive foundries across the U.S. In 1997, the metal casting industry spent $1.2 billion on fuels and purchased electricity, representing about 10% of all material costs in the

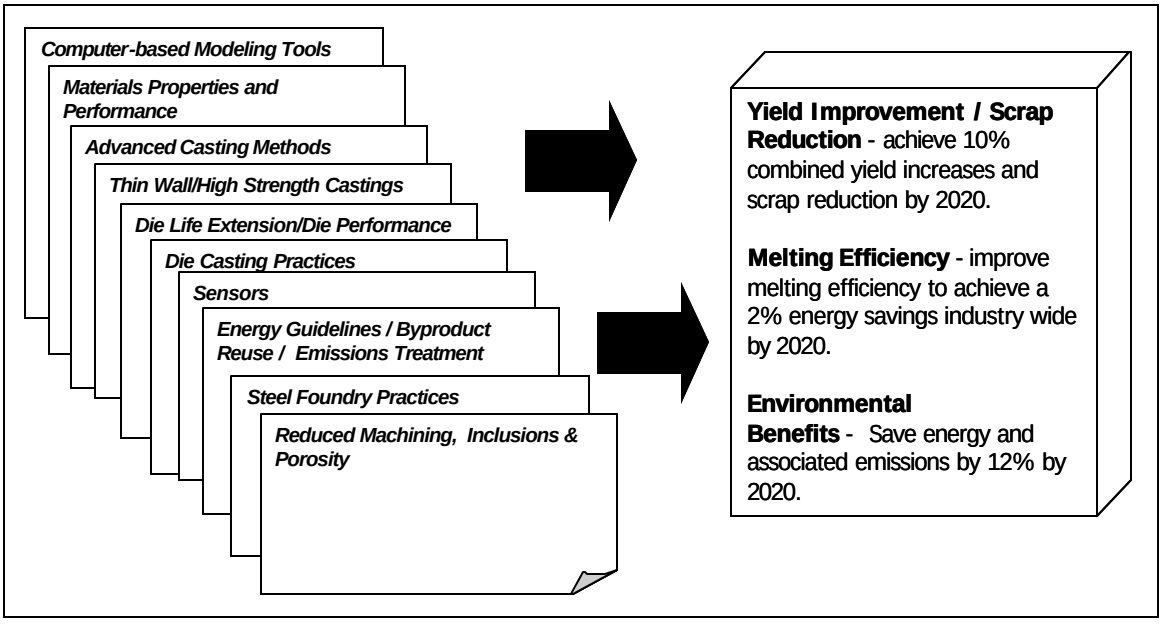
[1] *Energy and Environmental Profile of the U.S. Metalcasting Industry,* U.S. Department of Energy, Office of Industrial Technologies, p. 10.

industry. Electricity met 65% of the industry's energy needs with the remaining 35% coming from natural gas, coke, coal, and petroleum.[2] Major energy consuming processes in metal casting include:

- melting
- coremaking
- moldmaking
- heat treatment, and
- post-cast activities

The most energy intensive of these processes is melting. Melting accounts for an estimated 55% of process energy costs.[3] Each year, the Program reports to Congress its progress in achieving energy goals in response to the Government Performance and Results Act (GPRA). To better assess this progress, the Program has identified specific performance measures. These performance measures and targeted areas of research to address them are illustrated in Exhibit 3. Additional information on the energy benefits of metal casting research is provided in Section 4. Cost-shared research performed through the Metal Casting Industry of the Future is helping to improve energy efficiency in the industry, addressing both national and industry objectives. This research is resulting in advances in cutting edge process improvements in the areas of casting design, materials, and manufacturing. It is directly contributing to progress in these performance measures.

Exhibit 3
Targeted Research Addresses Key Performance Measures



[2] Source: U.S. Department of Commerce, U.S. Census Bureau, 1997 Economic Census, Manufacturing Industry Series, Table 3, Detailed Statistics by Industry, 1997

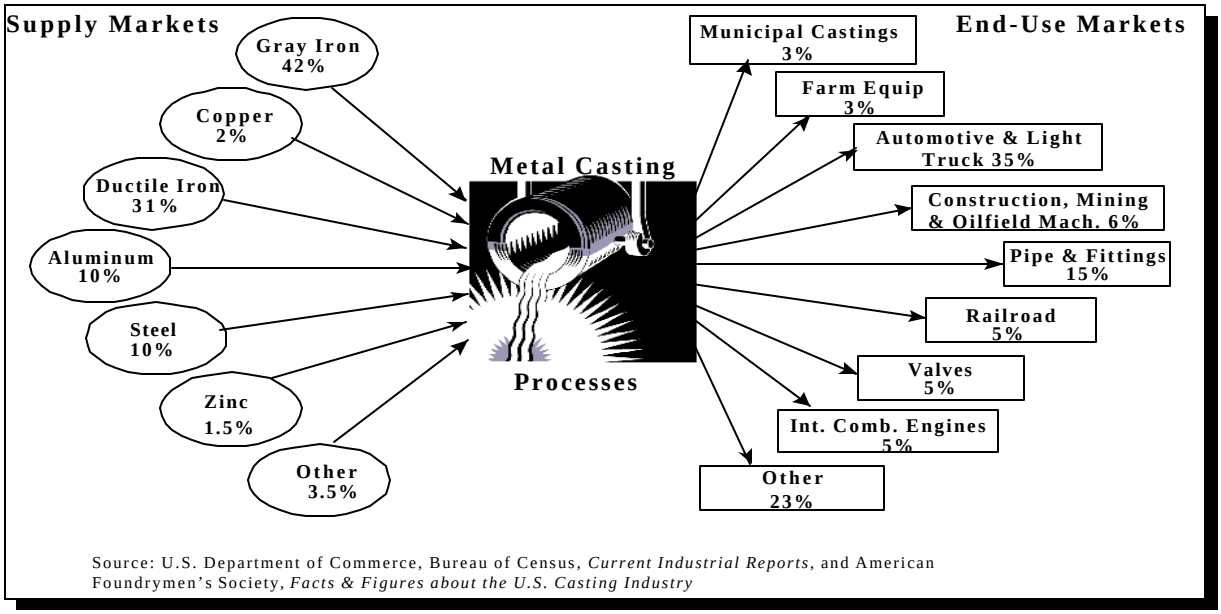
[3] ibid.

METAL CASTING IN BRIEF

Metal casting enables the production of simple to complex parts that meet a variety of needs. The process consists of pouring molten metal into a mold containing a cavity of the desired shape. The most widely used method for small to medium-sized castings is green sand molding. Other casting and molding processes include shell molding, permanent molding, investment casting, plaster molding, and die casting. In addition, there are a number of innovative and relatively new casting methods such as lost foam casting and squeeze casting.

A vibrant, competitive and energy-efficient U.S. metalcasting industry is vital to the U.S. economy and national security. Cast metal products are found in virtually every sector of the economy. Almost 90 percent of all manufactured products contain one or more metal castings .[4] Cast manufactured components include automotive parts such as engine blocks, transmission housings and suspension parts. Castings also are used in parts for pumps and compressors, pipes and fittings, mining and oil field equipment, recreational equipment, surgical equipment, and in many other areas. Exhibit 4 illustrates supply and end-use markets for castings. Markets for castings are increasingly competitive and customers for cast metal products are placing greater demands on the industry for high quality, competitively priced castings. In the industry's largest market, the automotive sector, customers are increasingly demanding light-weight, high strength cast metal components to respond to fuel economy requirements.

Exhibit 4
Casting Supply and End-use Markets



Source: U.S. Department of Commerce, Bureau of Census, *Current Industrial Reports*, and American Foundrymen's Society, *Facts & Figures about the U.S. Casting Industry*

[4] James P. LaRue, Ed.D. 1989. *Basic Metalcasting.* American Foundry Society

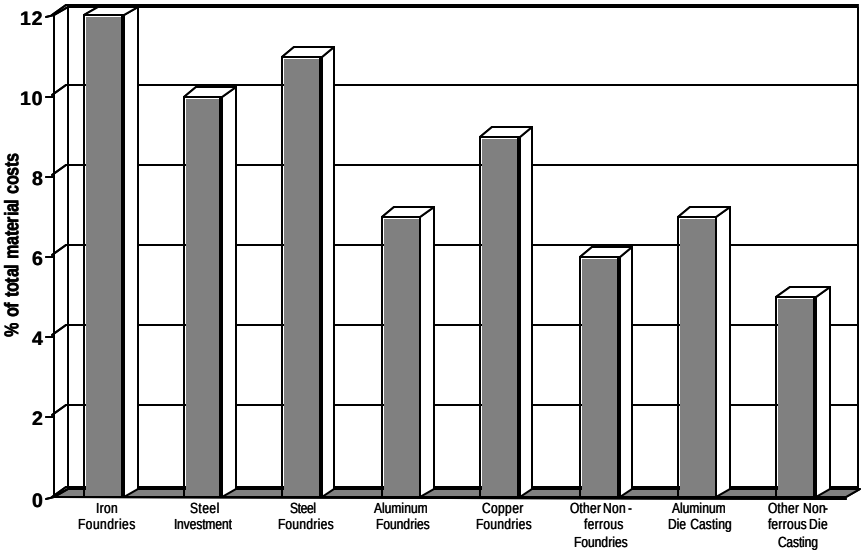
The metal casting industry is nationwide. There are 2,950 foundries located throughout the U.S. employing 225,000 people. The majority of metal casting facilities are small businesses. Eighty percent of foundries employ less than 100 people. Fourteen percent employ 100 to 250 people and six percent employ more than 250 people. Although the industry is found nationwide, seven states accounted for nearly 75% of all casting shipments. These include Ohio, Indiana, Wisconsin, Alabama, Michigan, Pennsylvania, and Illinois.[5]

Metal Casting Industry Energy Expenditures

Energy costs in the metal casting industry were over $1.2 billion in 1997.[6] Industry-wide, energy represents 10% of total material costs. This was highest in iron foundries where energy represented 12% of total material costs, and lowest in non-ferrous die casting facilities where energy represented 5% of total material costs. Exhibit 5 illustrates energy costs as a percentage of total material costs for each of the sectors within the metal casting industry. Industry-wide, energy costs represented about 4% of the value of shipments.[7]

Data on energy purchases are provided in Exhibit 6. Energy costs as a percentage of total material costs and as a percentage of the value of shipments are expected to increase for 2000 as a result of increased energy prices.

Exhibit 5
Energy Costs in Metal Casting Relative to Total Material Costs



Source: U.S. Department of Commerce, U.S. Census Bureau, 1997 Economic Census, Manufacturing Industry Series, Table 3, Detailed Statistics by Industry: 1997 for metal casting industry NAICS codes.

The metal casting industry purchased 15.7 billion kWh in 1997 – comparable to the combined electricity consumed annually by residents in New Hampshire, New Mexico, Rhode Island,

[5] American Foundry Society, *Facts & Figures about the U.S. Foundry Industry.*

[6] Does not include captive foundries.

[7] U.S. Department of Commerce, U.S. Census Bureau, 1997 Economic Census, Manufacturing Industry Series, Table 3, Detailed Statistics by Industry: 1997 for NAICS codes 331511, 331512, 331513, 331524, 331525, 331528, 331521, and 331522. These data are collected by the Economic Census every five years for years ending with a two and a seven.

Wyoming, and Hawaii. Sixty-five percent of the industry's energy costs were for purchased electricity. The remaining 35% went towards fuels.[8]

Exhibit 6
Energy Costs for the Metal Casting Industry, 1997 (million dollars except as noted)

	Cost of Fuels	Cost of Purchased Electricity	Cost of Fuels + Purchased Electricity	Total Cost of Materials	Energy Costs as a % of Material Costs	Electricity Purchased for Heat & Power ('000 kWh)
Iron Foundries (331511)	$224.3	$422.3	$646.5	$5,174.8	12%	8,946,469
Steel Investment foundries (331512)	20.2	50.5	70.7	715.3	10%	866,668
Steel Foundries except investment (331513)	39.8	92.1	131.9	1,174.6	11%	1,981,163
Nonferrous (except aluminum) die casting	16.7	32.3	49.0	901.2	5%	512,545
Aluminum foundries (except Die Casting)	49.9	70.6	120.4	1,743.7	7%	1,429,554
Copper foundries (except die casting) 331525	7.5	21.8	29.2	341.7	9%	363,833
Other non-ferrous Foundries except die	7.1	14.5	21.6	363.4	6%	274,186
Aluminum Die Casting foundries (331521)	54.7	70.2	124.8	1,842.1	7%	1,351,440
Total	**$419.0**	**$774.2**	**$1,194.1**	**$12,256.8**	**10%**	**15,725,858**

Source: U.S. Department of Commerce, U.S. Census Bureau, 1997 Economic Census, Manufacturing Industry Series, Table 3, Detailed Statistics by Industry: 1997 for NAICS codes 331511, 331512, 331513, 331524, 331525, 331528, 331521, and 331522.

Metal Casting Industry Shipments

As shown in Exhibit 7, casting shipments decreased less than one percent between 1998 and 1999. This was due in part to a drop in steel and gray iron castings which declined 9.3%, 123,035 short tons, and 1.7%, 100,901 short tons respectively. These declines were offset however due to continued growth in ductile iron castings for pressure pipe and automotive uses. Ductile iron shipments increased 3.8% or 172,783 short tons over the period. Declines were also offset by increased shipments of non-ferrous castings which increased across all categories of non-ferrous alloys. Aluminum and aluminum-

[8] Ibid

based alloys accounted for the largest share of the increase shipping 119,810 short tons more in 1999 than in 1998. The value of casting shipments for 1998 and 1999 are provided in Exhibit 8. Although the quantity of castings decreased less than one percent over the period, the value of shipments decreased 3.1%. This was due largely to a drop in the value of shipments for iron and steel castings. In addition, the value per ton of aluminum casting shipments dropped over the period.

Exhibit 7
U.S. Producers' Shipments of Non-ferrous and Ferrous Castings (short tons)

Non-ferrous Castings	**1997**	**1998**	**1999**	**% change (98-99)**
Aluminum and aluminum-based alloy	1,593,876	1,921,137	2,040,947	6.2
Copper and copper-base alloy	276,480	286,360	309,843	8.2
Magnesium and magnesium-base alloy	19,257	20,741	22,611	9.0
Zinc and zinc-base alloy	228,933	239,169	242,439	1.4
Lead and Lead-base alloy die	163,580	169,639	182,927	7.8
Total Non-ferrous	2,282,126	2,637,046	2,798,767	6.1
Ferrous Castings	**1997**	**1998**	**1999**	**% change (98-99)**
Ductile Iron	4,324,723	4,582,567	4,755,350	3.8
Gray Iron	5,937,606	6,047,019	5,946,118	-1.7
Malleable Iron	271,763	246,823	207,328	-16.0
Steel[1]	1,218,452	1,324,914	1,201,879	-9.3
Total Ferrous	11,752,544	12,201,132	12,110,675	-0.7
Total Non-ferrous and Ferrous	**14,034,670**	**14,838,178**	**14,909,442**	**0.5%**

1. Does not include steel investment castings.

Source: U.S. Department of Commerce, U.S. Census Bureau, *Current Industrial Reports*, Iron and Steel Castings 1999, MA331A(98)-1, Table 3; Non-Ferrous Castings 1999, MA331E(99)-1, Table 1.

Exhibit 8
Value of Shipments of Non-ferrous and Ferrous Castings ('000 dollars)

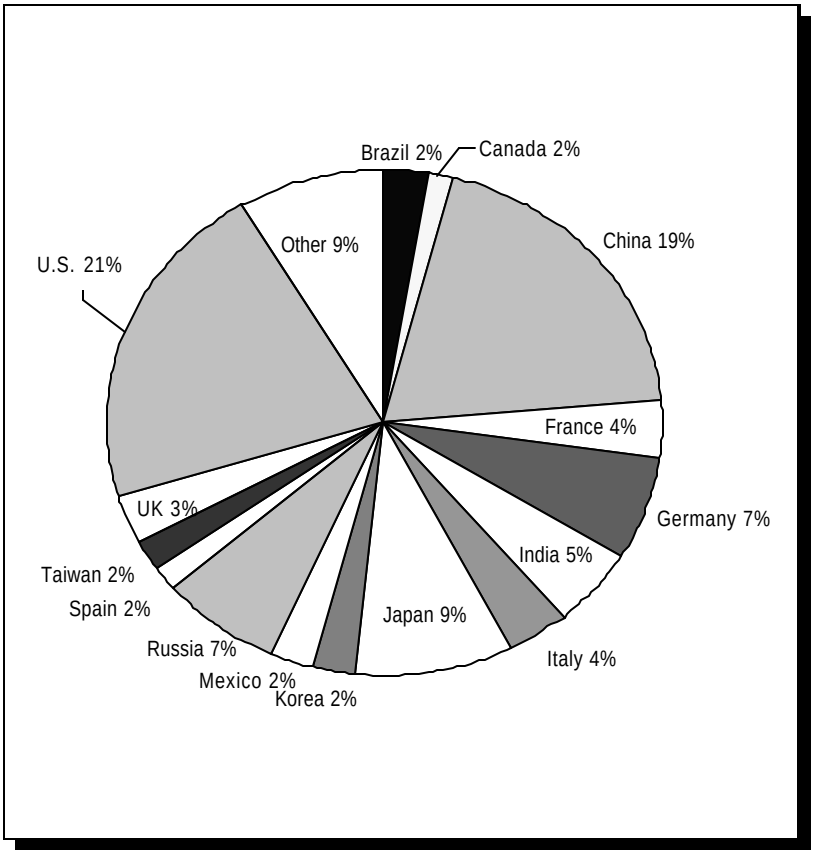
Non-ferrous Castings	**1997**	**1998**	**1999**	**% change (98-99)**
Aluminum and aluminum-based alloy	5,172,590	$5,669,532	$5,667,807	-0.1
Copper and copper-base alloy	991,974	1,053,833	1,121,712	6.4
Magnesium and magnesium-base alloy	225,685	256,852	254,840	-0.8
Zinc and zinc-base alloy	818,963	914,648	947,174	3.6
Lead and lead-based alloy die	9,909	8,407	6,665	-20.7
Total Non-ferrous	$7,219,121	$7,903,272	$7,998,198	1.2
Ferrous Castings	**1997**	**1998**	**1999**	**% change (98-99)**
Ductile Iron	4,148,900	$4,428,400	$4,384,700	-1.0
Gray Iron	4,719,500	4,635,100	4,429,700	-4.4
Malleable Iron	272,400	257,900	238,400	-7.6
Steel[1]	2,343,500	2,499,000	2,147,000	-14.1
Total Iron and Steel	$11,484,300	$11,820,400	$11,119,800	-5.9
Total Non-ferrous and Ferrous	**$18,703,421**	**$19,723,672**	**$19,117,998**	**-3.1%**

1. Does not include steel investment castings.

Source: U.S. Department of Commerce, U.S. Census Bureau, *Current Industrial Reports*, Iron and Steel Castings 1999, MA331A(99)-1, Table 2; and *Current Industrial Reports*, Non-Ferrous Castings 1999, MA331E(99)-1, Table 2.

Exhibit 9 illustrates market share of world casting production for 1999 based on tons produced. The U.S. continues to lead the world in casting shipments across nearly all metal types including ductile iron, steel, copper, aluminum and zinc. China is the world's leading producer of gray iron and malleable iron castings and India is the world leader in magnesium castings. China saw the strongest growth in castings shipments among leading world producers posting a 24% increase from 1998 production levels. This is due in part to increased economic growth in heavy industry in China. Among leading producers, casting shipments also increased in Korea (6.3%), Brazil (less than 1%), and Mexico (2.2%) in 1999. Casting shipments fell among other leading producers including Japan (4%), Germany (2.6%), India (4.3%), France (3.8%), and Italy (less than 1%).[9]

Exhibit 9
1999 World Casting Production - Share of Tonnage Produced



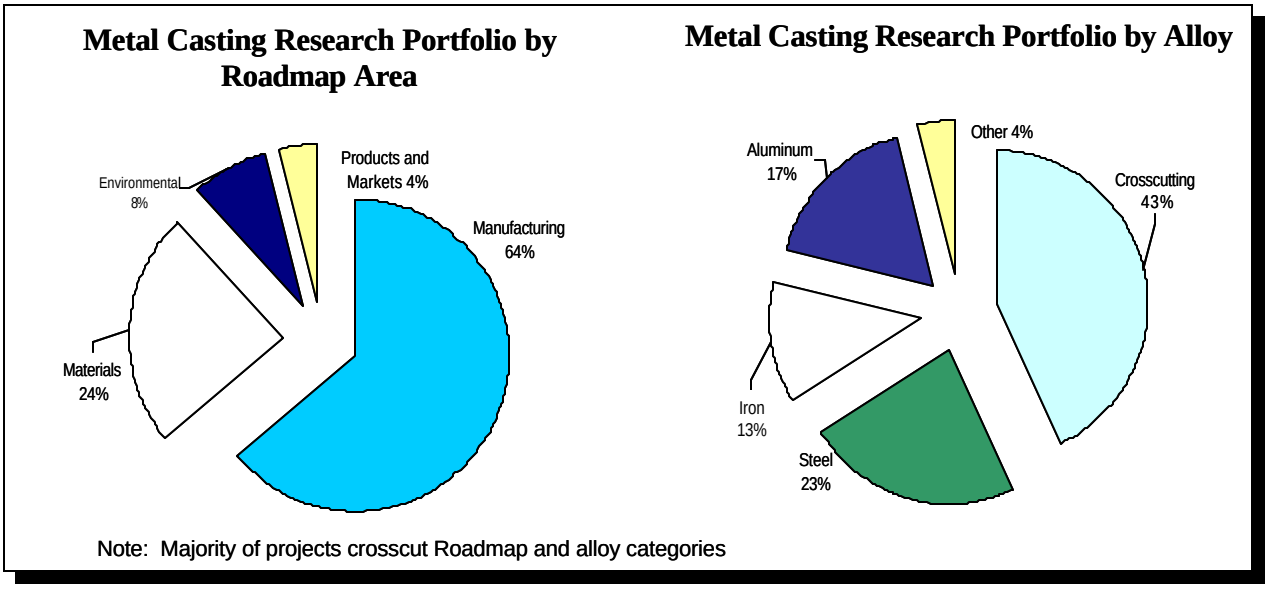
[9] Source: "33rd Census of World Casting Production – 1999", *Modern Casting*, December 2000, p. 30.

METAL CASTING RESEARCH PORTFOLIO

The Metal Casting Industry of the Future Program supports cost-shared, pre-competitive research, addressing national energy efficiency goals. The portfolio addresses high risk/high impact needs of the metal casting industry and has broad applicability throughout the U.S. The current Program portfolio consists of 53 active projects involving 320 partners from 35 states across the U.S. It emphasizes both energy efficiency, quality, and competitiveness.

The metal casting industry is diverse using numerous casting methods and casting various types of alloys. This requires careful attention to maintain a research portfolio that reflects both the diversity of the industry yet also has broad applicability across the industry. As shown in Exhibit 10, the metal casting portfolio addresses each of the key Roadmap areas outlined by industry in the areas of Products and Markets, Materials Technologies, Manufacturing Technologies, and Environmental Technologies. Because the greatest advances in energy efficiency will be achieved through improvements in manufacturing, the majority of metal casting research funding is in the area of manufacturing technologies. Also shown in Exhibit 10, the portfolio includes research projects tailored to virtually all categories of ferrous and non-ferrous alloys. Yet the majority of metal casting research has applications that cut across all alloys.

Exhibit 10
Diverse Metal Casting Research Portfolio



Appendix C provides brief summaries of current projects and partners in the Metal Casting Industry of the Future research portfolio. Projects are listed by the primary Roadmap area that they address. Most projects in the portfolio, however, relate to multiple Roadmap areas. For example, the project "Energy Consumption in Die Casting Operations" addresses the Manufacturing Technologies section of the Roadmap by investigating methods to improve energy efficiency in die casting manufacturing processes. However, it simultaneously relates to the Environmental Technologies section of the Roadmap by addressing important environmental requirements facing the industry.

Integrated Delivery: Providing An Array of Technical and Financial Assistance to the Metal Casting Industry

The Office of Industrial Technologies performs a wide range of activities relevant to metal casters. In addition to research the OIT Metal Casting Industry of the Future supports, OIT's Integrated Delivery Strategy includes technical and financial assistance, and advanced research on crosscutting technologies.

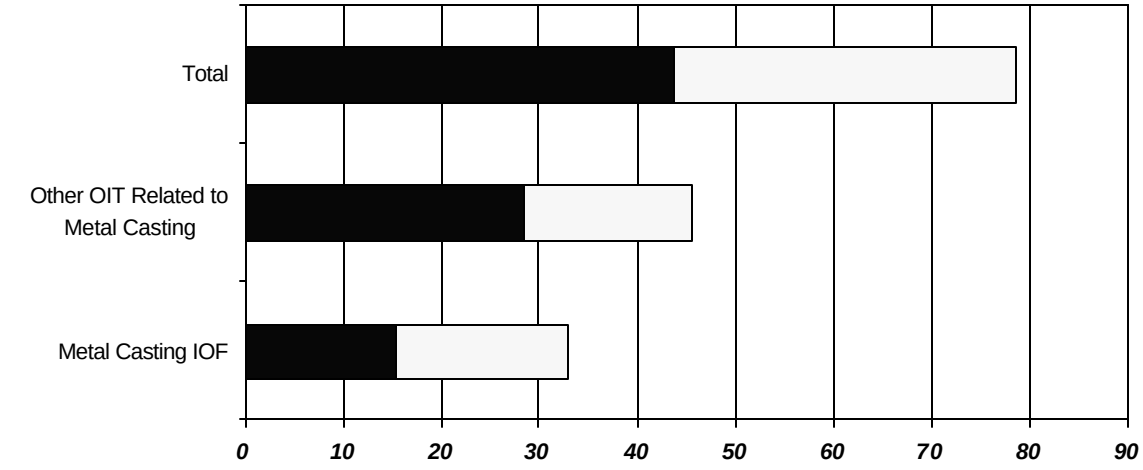
- Research in Industrial Materials is evaluating durable materials that can withstand harsh, high-temperature industrial environments.
- Research in Sensors and Controls is improving sensor accuracy and reach in harsh environments.
- OIT's BestPractices program and university-based Industrial Assessment Centers are performing energy audits and offering energy and cost saving advice to metal casters. One recent assessment made recommendations that have the potential to reduce costs by $3.7 million annually.
- Finally, research is being performed by several of the other Industry of the Future programs, including the Steel and Aluminum IOFs, that has particular interest to metal casters.

As shown in Exhibit 11, OIT has provided nearly $44 million in recent years to support research and technical assistance relevant to metal casters. This investment has leveraged nearly $35 million in additional research funding from industry cost share. The following lists OIT research projects, outside of the Metal Casting Industry of the Future program relevant to metal casters. For summaries of Metal Casting Industry of the Future research specifically, please refer to Appendix C.

- *In-Situ, Real Time Measurement of Melt Constituents in the Aluminum, Glass, and Steel Industries (Energy Research Company, and FutureTec Management Systems)*
- *A Ceramic Composite for Metal Casting (MER Corporation)*
- *Titanium Matrix Composite Tooling Material for Enhanced Manufacture of Aluminum Die Castings (Dynamet Technology, Inc.)*
- *Advanced Intermetallic Alloy for Ethylene Reactors (Oak Ridge National Laboratory)*
- *Filtering molten metal (Palmer Manufacturing and Supply)*
- *Development of an innovative vertical floatation melter and scrap dryer (Energy Research Company)*
- *Improved grain refiner process for aluminum (JDC Associates)*

- *Advanced process control program for the steel industry: Optical Sensors and Controls for Improved BOF operation, microstructure engineering in hot strip mills, temperature measurement of galvanneal (American Iron and Steel Institute)*
- *Removal of residual elements in the steel ladle by a combination of top-slag and deep injection (McMaster University, American Iron and Steel Institute)*
- *An optical sensor for post-combustion control in electric arc steelmaking (Sandia National Laboratory, Goodfellow Technologies)*
- *Development of an Innovative energy efficient high temperature natural gas fired Furnace (Procedyne Corporation)*
- *Reducing foundry emissions and green sand waste via integrated advanced Oxidation-Underwater plasma processing (Advanced Cast Productions)*
- *A process to recover and reuse sulfur dioxide in metal-casting operations (Adsorption Research, Inc. and Ohio Department of Development)*
- *Novel method to process electric arc furnace dust into saleable chemical products*
- *(Drinkard Metalox)*

Exhibit 11
Leveraging Funding for Metal Casting Research:
Estimated Funding FY'99 - '01



	Metal Casting IOF	*Other OIT Related to Metal Casting*	*Total*
□ *Industry Cost Share*	*$17.60*	*$17.10*	*$34.70*
■ *OIT Funding*	*$15.30*	*$28.50*	*$43.80*

million dollars

METAL CASTING IMPACTS & ACCOMPLISHMENTS: 2000

The Metal Casting Industry of the Future Program posted a number of important accomplishments during 2000. Technologies resulting from this research continue to be adopted by industry. The following describes highlights from 2000.

University-Based Research

The availability of a well-trained labor force in the U.S. metal casting industry has been one of the industry's top priorities. It is a concern across all of the U.S.'s base industries. Addressing this concern, the Metal Casting Industry of the Future places a strong emphasis on university-based research. Program-funded research is performed at nearly 20 universities across the U.S. U.S. students are being introduced to cutting-edge technology and materials research critical to the future health of the U.S. economy. In addition to successfully guiding well-trained students to productive careers in the industry, this approach has the double benefit of accessing the resources of some of the leading metal casting expertise in the country. The involvement of universities is resulting in the education of tomorrow's metal casting industry leaders. Upon entering the industry, these students are able to translate their education in the advanced technologies, materials, and processes into improved energy efficiency and productivity for industry. To further build upon the benefit of University-based research, the Metal Casting Industry of the Future recently began to develop an Alumni Network of students who have been involved on Metal Casting IOF projects. This network can be used as a forum for additional technology and information transfer of energy saving measures and technology advances.

High School Engineering Challenge

In November 2000, high school students from 2,000 high schools across the U.S. took the Junior Engineering Technology Society test which included test questions designed specifically for metal casting. The winning team for the Metal Casting question, from Saginaw, Michigan, was invited to OIT's 4th Energy Efficiency Symposium and Exposition in February 2001 to present their results in a poster presentation. The goal of the High School Challenge was to introduce young students to the field of metal casing and the other Industries of the Future as they consider their college curricula.

Significant Technical Accomplishments in Metal Casting Research

The Metal Casting Industry of the Future R&D portfolio made important contributions to Roadmap priorities as well as OIT's energy performance metrics during 2000. Several highlights include:

- **Lead-free Plumbing Alloy Development and Copper Permanent Mold Casting (Materials Technology Laboratory)** - The mechanical, fracture toughness, impact, and fatigue properties of 13 copper alloys have been established. For the first time, a comprehensive database on mechanical, impact, fatigue, fracture toughness as well as wear and corrosion properties is available for these alloys. The mechanical properties were incorporated by the Copper Development Association in their publications and will be proposed for ASTM specifications. In addition, a new low-melting copper alloy suitable for permanent mold casting was developed. This alloy contains zinc (20-25%), nickel (4-5%), phosphorous (3-5%), and aluminum (0.5%) as the major alloy additions.

- **Lost Foam Casting (University of Alabama - Birmingham)** - As a result of the partnership among academia, industry and DOE, lost foam production is increasing rapidly, estimated as much as 20% per year. Lost Foam Casting has significant cost and environmental advantages and enables metal casters to produce complex parts that are often not possible using other methods. The process allows designers to consolidate parts, reduce machining and minimize assembly operations. It also allows foundries to reduce solid waste and emissions. This research has resulted in significant improvements in lost foam process controls. Research indicates a total energy savings of about 27% coupled with a 46% improvement in labor productivity and the use of about 7% by weight fewer materials in lost foam casting compared to green sand or resin bonded sand molding. The involvement of DOE and the Lost Foam Casting Consortium has been called the "driving force" behind many of the improvements in lost foam.

- **Composition and Processing of High Performance Die Steels Effects Performance (Case Western Reserve University)** - Immersion tests have shown that the thermal fatigue resistance of specially processed die steels of selected compositions is superior in performance to other die steels that have been employed in the past. The processing should include VAR or EST melting to provide closely controlled alloy segregation and a minimum amount of inclusions. Steels processed in this manner also have controlled limits on the silicon, vanadium, molybdenum and chromium contents as well as a low sulfur and oxygen content. The result is superior behavior in thermal fatigue cracking. When properly implemented, this process results in considerable improvement in die life with a substantial savings in die cost. A die life improvement of 50% to 100% is normally obtained.

- **VOC Emissions Reduction (Pennsylvania State University)** - Tests using Advanced Oxidation (AO) systems to reduce VOC emissions at green sand foundries have been positive. At the Neenah Foundry, AO technology has reduced sand system bond usage by 15 percent with an associated reduction in emissions from cooling and shakeout. At International Truck & Engine's Waukesha plant, stack tests conducted in 1999 showed a 56 percent reduction in benzene per ton of iron poured and a 74 percent reduction of VOCs (including benzene) per ton of iron poured. Tests have also demonstrated that CO emissions have been reduced by 10 percent as a direct result of sand system optimization. Significant cost reductions have been achieved at both foundries due to reductions in sand system clay (bond) requirements.

- **Aluminum Alloy Microstructure Performance Interactions (Worcester Polytechnic Institute)** - As a result of this research, the die casting industry now has available a database explained the effects of key elements on the properties of the die cast product. This permits a tailoring of alloy compositions to optimize the die casting process for specific applications. This work became the basis for a book "Alloy Chemistry-Mocrostructure-Properties Interactions in Aluminum Die Casting Alloys" published by the North American Die Casting Association. The book is extensively used as a database and a guide by the aluminum die casting industry.

These research results are helping the industry to improve competitiveness in U.S. and world markets while meeting increasingly demanding requirements for light-weight, high-strength, dimensionally accurate, complex castings. Simultaneously, progress is occurring to improve energy efficiency through higher yield, reduced scrap, and improved melting efficiency. Information on research accomplishments is published in the *CMC Annual Report 2000*. Research results are also available through the CMC in its newsletter *Cast Metal Research Review*, trade journals, technical reports, the DOE website (www.oit.doe.gov), seminars, conferences and expositions.

Technology Transfer: Applying Research Results in Industry

The Metal Casting Industry of the Future employs a multifaceted strategy for technology transfer. This includes reporting technical results in trade journals, presentations at both national conferences and local chapters of industry societies, OIT Expo, and dissemination of project information through fact sheets, Annual Reports, and other materials, and other methods. Equally important is the direct involvement of hundreds of industry partners that provide cost-shared support on metal casting research. They are applying the results of Metal Casting IOF research on a real-time basis. Examples include:

- *Die casting die life extensions are up to 50% based on cast steel R&D.*
- *Thousands of pounds of aluminum were saved in one metal casting facility through a database on properties developed through OIT-sponsored R&D -- applicable industry-wide.*
- *Lost Foam production is growing at 20% per year. For example, Teksid SpA is constructing a lost foam casting facility in Sylacauga, AL that will produce an estimated 65 million pounds of engine castings per year.*
- *Falk Corporation & Harrison Steel Casting are converting their production to shroud pouring as a result of the clean cast steel research.*
- *Using results of refractories research, Grede Foundries uses a castable alumina bottom in its arc furnace.*
- *Kennedy Die Casting uses an alloy developed through IOF research for electronics.*
- *Improved in-plant process efficiencies achieved through reduced materials handling*
- *Southwest Steel and Sawbrook Steel have improved process efficiencies through reengineering production layouts*

OIT Showcases, OIT Industrial Assessment Centers, and OIT BestPractices are also being used to disseminate the results of research. For example, through its BestPractices program OIT performed a plant-wide industrial energy assessment of AMCAST Industrial Corporation's aluminum casting plant in

Wapakoneta, Ohio. The assessment resulted in 13 recommendations for process improvements and plant modifications with an expected savings of $3.7 million annually and emissions reduction of 11 million pounds of CO_2. OIT is disseminating the resulting recommendations for saving energy in metal casting facilities throughout the industry. Some of the recommendations include:

- using electric infrared heaters to pre-heat dies
- using a new method for sprue melting
- using exhaust heat from reverberatory melt furnaces in heat treating furnaces
- using exhaust heat from heat treating furnaces in aging ovens
- installing adjustable speed drives on casting machines

Conference presentations are a popular means of bringing both research results and the researchers to the industry. A technical paper on *CastView* written for the North American Die Casting Association Inaugural Die Casting Congress won "Best Paper" in the Implementation of R&D session of the Congress. CastView is a PC-based modeling program for die casting flow simulation. It was designed to be CAD-system independent. It takes complex geometric models and enables the user to quickly identify possible problem areas in the design process. It provides quick results, produces output files that can be transferred via the Internet, and reduces the need for costly, energy intensive die tryouts.

During 2000 a number of articles on program-funded research appeared in trade journals such as *Die Casting Engineer*, *Foundry Management & Technology*, and *Modern Casting*. Examples include:

- "Development Studies on Selection & Processing of Die Materials to Extend Die Life" (Die Casting Engineer, May/June 2000)
- "Research in Action: Implementation of Die Material Testing" (Die Casting Engineer, May/June 2000)
- "Using an Ergonomic Approach in your Operation" (Modern Casting, Oct. 2000)
- "Advanced Oxidants Offer Opportunities to Improve Mold Properties, Emissions" (Modern Casting, Sept. 2000)
- "Speakers Focus on Improving Melt Efficiency, Process Control" (Modern Casting Nov. 2000)
- "A Look Back at the 20th Century: Lost Foam Casting" (Modern Casting, Nov. 2000)
- "Process Control in Squeeze Casting"(Die Casting Engineer November/December 2000)

Information is also available through OIT fact sheets and program reports. These are available on the OIT website at <www.oit.doe.gov> and from the OIT Clearinghouse at (800) 862-2086.

Upcoming Milestones

Exhibit 12 shows key research milestones for 2001 through 2004. The application of these research results in industry will further enhance the ability of the U.S. metal casting industry to improve competitiveness and energy efficiency.

Exhibit 12
Planned Milestones

2001
• Residual Stress - Design Guidelines • Fast Shot Transition Point- Shot Profile Guidelines • Qualitative Reasoning – 3-D Shrinkage, Cooling Line Placement • Semi-solid Metals – 2 Phase Flow Model (Commercial) • Thin Wall Iron Casting -Critical Variables in Molding Accuracy Guideline • Clean Cast Steel - New melting practice models developed and on trial. • Yield Improvement in Steel Castings - New feeding distance rules published for carbon & low alloy steels. • Thin Wall Iron Castings - Guidelines published. • Impurity Limits in Aluminum Bronzes - Composition limits added to CDA Handbook • Design Parameters for Permanent Lead Free Copper • Base Alloy Castings - Properties published in CDA "Casting Copper-Based Alloys"
2002
• Thin Wall Iron Castings -Metal Treatment Best Practices for Thin Section Iron Castings • Lost Foam - Foam Decomposition Model for Quality Control and Coating Development • Die Materials – Recommendations for Productivity Improvement • Reengineering Casting Production Systems - Reorganizing finishing operations to use robotic finishing to improve productivity and safety. • Impurity Limits in Aluminum Bronzes - ASTM vote on modification to B148, Aluminum Bronze Standard
2003
• Yield Improvement in Steel Castings - Radiographic Standards; Production Approval (30% scrap reduction) • Die Deflection - Enhanced Tolerances • Die Coatings- Multi-layer System Recommendation
2004
• Lost Foam - "Gating" Rules Based on Real-time Radiography Evaluation • Sensors – Vibration Signatures for Die Casting Process Control • Creep Resistant Zinc – New Die Casting Alloy

Partnership Highlights

In 2000, the Program made dramatic progress in broadening the reach of the Metal Casting Industry of the Future partnership. Participation from industry, universities, and others increased from 250 partners in 1999 to 320 in 2000. This broad participation is providing a direct avenue for dissemination of research results.

State Industries of the Future

Simply by applying the Industries of the Future model, the State-level IOF program is fostering partnerships among state agencies and local industry to address local energy, environmental, and economic needs. State IOFs pursuing activities in metal casting include Massachusetts, Michigan, Wisconsin, New Hampshire, Ohio,

Iowa, Pennsylvania and others. Several notable accomplishments were made in the metal casting community as a result of the State Industries of the Future strategy. These include:

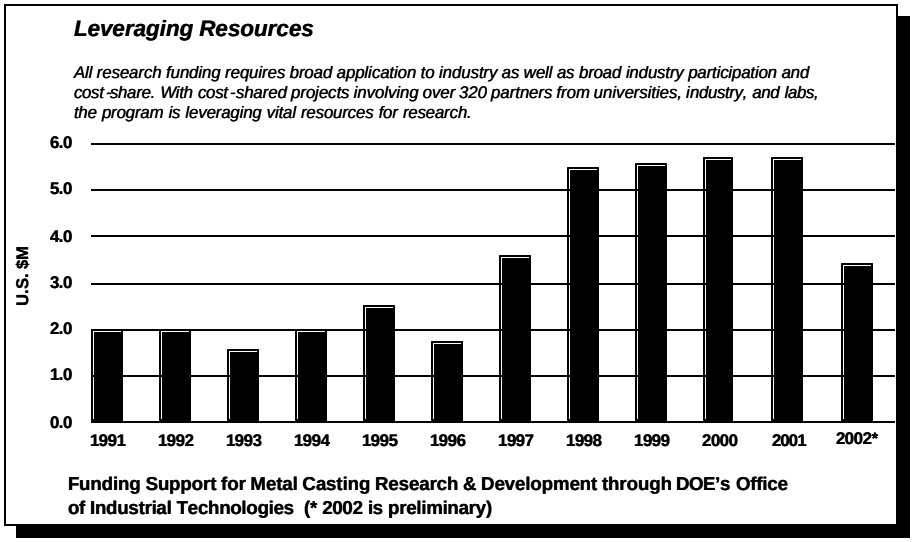
- **Spent Foundry Sand** - The West Virginia IOF Metal Casting Group succeeded in reclassifying spent foundry sand as a recyclable material resulting in *Spent Foundry Beneficial Use Guidelines* published by the State's Division of Environmental Protection and effective June 1, 2000. Prior to June 2000, foundry sand had been classified as an industrial waste in West Virginia and needed to be landfilled. These guidelines will reduce waste management costs for the industry and allow nonhazardous spent foundry sand to be used for other materials including flowable fill for highway construction and other products. Carl Irwin, who championed IOF-WV, exclaimed that this example "shows that committed people working through a State IOF process is a strategy for success!" It demonstrates how the State IOF strategy can be a vehicle for addressing local and regional issues.

- **Wisconsin Metal Casting Roadmap** - Using the State IOF approach, the Wisconsin Energy Bureau worked with stakeholders from industry, universities and others to develop a Wisconsin Metal Casting Roadmap. The Roadmap is forming the basis for future Wisconsin IOF activities related to metal casting.

Leveraging Resources

The program continues to maximize limited resources to co-fund high impact metal casting research. Along with industry cost-share requirements, the program leverages technical expertise from industry and academia as well as other research programs. DOE funding for the Metal Casting Program is shown in Exhibit 13.

Exhibit 13
Metal Casting Program Funding



New Project Awards

The Program's annual solicitation for competitive cost-shared research proposals resulted in twelve awards. They are listed in Exhibit 14. The ensuing research projects will make important contributions to ongoing efforts to address Vision targets and national energy efficiency goals. In making these awards, new research organizations were added to the long list of research performers participating in OIT's metal casting research. These include: Colorado State University, Prince Machine, and Arena, LLC.

Exhibit 14
FY 2000 Metal Casting Research Awards

Project Title	Project Lead
Computer modeling of the mechanical performance of die casting dies	Ohio State University
Development of technical data to validate performance of foundry by-products for hot-mix asphalt and controlled low-strength material	Pennsylvania State University
Service performance of welded duplex stainless steel castings and wrought material (Part II)	University of Tennessee
Ultrahigh-speed measurement of internal die cavity temperature profiles for process control and model verification	Prince Machine
Grain refinement of permanent mold cast copper base alloys	Materials Technology Laboratory
Castability assessment and data integration	Ohio State University
Development of computational fluid dynamics tool for modeling the blowing and steaming of expandable polystyrene patterns for lost foam	Arena, LLC
Metallic reinforcement of direct squeeze die cast aluminum alloys for improved strength and fracture resistance	Case Western Reserve
Prevention of porosity in iron castings	Climax Research Services
Integration of RSP tooling with rapid prototyping for die casting applications	Colorado State University
Gating of permanent mold aluminum casting	Case Western Reserve University
Improvements in sand/mold/core technology: Effects on casting finish	Ohio State University

Making Progress on Energy Metrics

All cost-shared research performed through the Metal Casting Industry of the Future is helping to improve energy efficiency in the industry, addressing both national and industry objectives. Each year, the Program reports to Congress its progress in achieving energy goals in response to the Government Performance and Results Act (GPRA). To better assess this progress, the Program has identified specific performance measures including: 1) yield increases and scrap reduction; 2) melting efficiency; and 3) environmental benefits. To respond to these performance measures the Metal Casting Industry of the Future is conducting research in a number of areas including:

- Computer-based modeling tools
- Die-life Extension/Die Performance
- Material Properties Performance
- Thin-wall / High Strength Castings
- Advanced Casting Methods
- Sensors
- Reduced Machining, Inclusions and Porosity
- Energy Guidelines / Byproduct Re-use / Emissions Treatment
- Foundry Practices
- Die Casting Practices

Exhibit 15 provides illustrates selected projects, categorized by the above research areas, and their expected year of market introduction. Projects in each of these areas will help to improve energy efficiency. They are advancing cutting edge design, materials and processing, and manufacturing technologies that directly contribute to progress in these performance measures. Applied in the metal casting industry, it will save energy through improvements in manufacturing efficiency, materials performance, and casting practices.

Exhibit 15
Research to Improve Energy Efficiency in Metal Casting Processes

Metal Casting Process / Research Category	Project Name	Anticipated Year of Introduction
Computer-based Modeling Tools - Improves design integrity and reduce requirements for plant trials thereby reducing melting requirements and scrap.	Development of computational fluid dynamics tool for modeling bead expansion in lost foam	2003
	Computer modeling of the mechanical performance of die casting dies	2003
	Qualitative reasoning for additional die casting design applications	2002
Die Life Extension/Die Performance - Reduces requirements in die development and tryout, and overall downtime, increasing energy efficiency and productivity.	Surface Engineered Coatings for Die Casting Dies	2003
	Integration of RSP Tooling in die casting	2003
Reduced machining, inclusions & porosity - Reduces defects and scrap as well as energy associated with post-cast operations.	Clean Steel Casting	2000
	Prevention of porosity formation and other effects of gaseous elements	2003
	Improvements in sand/mold/cor technology: effect on casting finish	2002
Thin Wall/High Strength Castings - Reduces melting requirements and improves competitiveness of cast products.	Thin wall cast iron	2003
	Clean, machinable thin walled gray and ductile iron casting	2002

Metal Casting Process / Research Category	Project Name	Anticipated Year of Introduction
Materials properties and performance (molds, dies, and castings) - Reduces casting defects and improve casting performance, thereby reducing scrap and increasing industry competitiveness.	Systematic microstructure corrosion performance of stainless steel	2002
	Mold Materials of Permanent Molding of Aluminum Alloys	2002
	Casting Characteristics of aluminum die casting alloys	2002
	Grain refinement of Permanent mold cast copper base alloys	2002
	Creep resistant zinc alloy development	2002
	Investment shell cracking	2002
	Service performance of welded duplex stainless steel castings	2002
Advanced casting methods - Advances state-of-the-art in cost-competitive, energy efficient casting processes.	Lost Foam	2000
	Metallic Reinforcement of the squeeze casting process	2003
Energy Guidelines / Byproduct Reuse / Emissions Treatment - Ready-to-implement guidelines to improve current energy, waste, and environmental needs.	Energy consumption in die casting operations	2002
	Non-incineration treatment to reduce benzene emissions	2002
	Technical data to validate foundry byproducts in hot mix asphalt	2002
Sensors - Speeds measurement capabilities improving productivity.	Sensors for die casting	2002
Foundry Practices - Identifies new gating, heat treating, process re-engineering, and other ready-to-implement methods for increasing yield and productivity and reducing melting requirements.	Re-engineering casting production systems and Ergonomic improvements of casting production systems	2000
	Yield Improvement in Steel Castings	2002
	Heat Treatment procedure qualification for steel casting	2002
Die Casting Practices - Identified new gating, process control, die filling and other ready-to-implement practices to improve yield and energy efficiency, reducing melting requirements.	Gating of aluminum permanent mold castings	2002
	Ultrahigh speed measurement of internal die cavity temperature for process control	2003
	Effect of externally solidified product on wave celerity	2002

Appendix A
Metal Casting Vision & Roadmap

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Metal Casting Vision & Roadmap

The U.S. Congress enacted the Department of Energy Metal Casting Competitiveness Research Act of 1990 (Public Law 101-425, 104 Stat. 915, 15 U.S.C. §5301-09) to improve the competitiveness and energy efficiency of the U.S. metal casting industry. The Act required the Secretary of Energy to establish a Metal Casting Competitiveness Research Program for the purpose of performing and promoting the performance of research and development on issues related to the technology competitiveness and energy efficiency of the U.S. metal casting industry. Under P.L. 101-425, the Program made significant contributions in the technical understanding of metal casting processes, manufacturing technologies and materials.

In 1995, the metal casting industry established a vision for the future in *Beyond 2000: A Vision for the American Metalcasting Industry*. The Vision outlines specific goals for the industry over the next 20 years. Research being funded through the Metal Casting Industry of the Future is helping to achieve these industry goals. Simultaneously, this research is helping to achieve national energy efficiency goals of the U.S. Department of Energy and the Office of Industrial Technologies. As stated in its Strategic Plan, major goals of OIT are:

> *"A 25 percent improvement in energy efficiency and 30 percent reduction in emissions for the vision industries by 2010."*
>
> *"A 35 percent improvement in energy efficiency and 50 percent reduction in emissions for the vision industries by 2020."*

The Strategic Plan states that "OIT will motivate and will assist industry to develop technology solutions to critical energy and environmental challenges..." thereby producing important national benefits. Through its partnerships with industry and open and competitive research solicitations, OIT is making significant progress in assisting industry to address these challenges.

Vision and Roadmap

The industry's 20-year Vision, *Beyond 2000: A Vision for the American Metal Casting Industry,* was developed by industry leaders including chief executive officers and presidents from the foundry, die castings, and foundry supply industries. The vision process was facilitated by the Office of Industrial Technologies. The Vision commits the metal casting industry to being:

- *the preferred supplier of net- or near-net-shape metal components,*
- *globally competitive,*
- *environmentally responsible,*
- *well capitalized and profitable,*
- *a source of challenging and well-paying careers,*

- *the world's benchmark for technology and innovation, and*
- *supportive of a strong supplier base.*

While Beyond 2000 identifies major needs of the metal casting industry, it is the *Metal Casting Industry Technology Roadmap* which outlines technology milestones needed to achieve Vision goals. The Roadmap represents the critical link between the broadly defined strategic goals contained in Beyond 2000 and the detailed research portfolio that will be pursued through industry-government partnerships. The Roadmap outlines pathways of near-term, mid-term and long-term research activities in four critical areas: Products and Markets; Materials Technologies; Manufacturing Technologies; and Environmental Technologies. Exhibit A-1 lists specific industry targets and research priorities in these four areas. The Metal Casting Industry of the Future annually solicits competitive, cost-shared research in these areas.

Exhibit A-1
Metal Casting Vision & Roadmap Goals[10]

TARGETS	INDUSTRY RESEARCH PRIORITIES
Products & Markets *-Recapture 25-50% of lost markets* *-Improve market share in current markets by 10%* *-Increase the rate of new market development*	• Transform foundries to tier-one suppliers. • Develop computer design tools to move from design concept to a design for manufacturing. • Develop methods to encourage/systematize concurrent engineering partnerships within the metal casting industry. • Develop ways to demonstrate the quality and value of castings. • Develop tools and technologies to reduce lead times in the metal casting industry.
Materials Technology *-Improve the variety, integrity, and performance of cast metal products*	▾ Develop quantitative relationships between alloy chemistries, properties and processing. ▾ Establish standard methodologies for materials testing. ▾ Develop a clean melting and remelting process. ▾ Develop methods for fast, accurate, and non-destructive evaluation of ingot and as-cast chemistries and properties (particularly for ferrous castings). ▾ Develop improved techniques to measure the acceptability of liquid metal prior to casting. ▾ Develop a national initiative to foster interest in materials science and engineering.
Manufacturing Technology *-Reduce energy consumption 20% by 2020* *-Increase productivity 15%* *-Reduce average lead time 50%*	▾ Develop low-cost rapid tooling technology. ▾ Improve tooling design to reduce the time to get castings to market. ▾ Develop cost-effective and dimensionally accurate patternmaking processes for use in sand casting. ▾ Improve the ability to produce size/dimension. ▾ Develop smart controls and sensors for automation supervision. ▾ Develop a systems approach to scheduling and tracking. ▾ Figure out how die casting molds/dies actually fill. ▾ Understand folds for aluminum lost foam casting. ▾ Develop melting and pouring technologies that do not introduce gases to the process. ▾ Develop a mathematical model that describes process control and can control the machine.
Environmental Technology *-Achieve 100% pre- and post-consumer recycling* *-Achieve 75% re-use of foundry by-products* *-Eliminate waste streams completely*	▾ Develop environmentally benign, dimensionally stable molding materials for sand casting. ▾ Develop new uses for waste streams and/or new ways to treat wastes to make them more usable. ▾ Develop emissions databases for foundries to use to educate regulators.

[10] Additional industry priorities are in the areas of: 1) Human Resources [to attract sufficient talent to the industry; and to keep present employees current with latest technologies and techniques]; 2) Profitability and Industry Health [to increase financial resources available to fund research and educational and marketing programs by 10%]; and 3) Partnerships and Collaborations [to encourage partnerships and collaborations to combine the experience, resources, and knowledge of available public- and private-sector organizations].

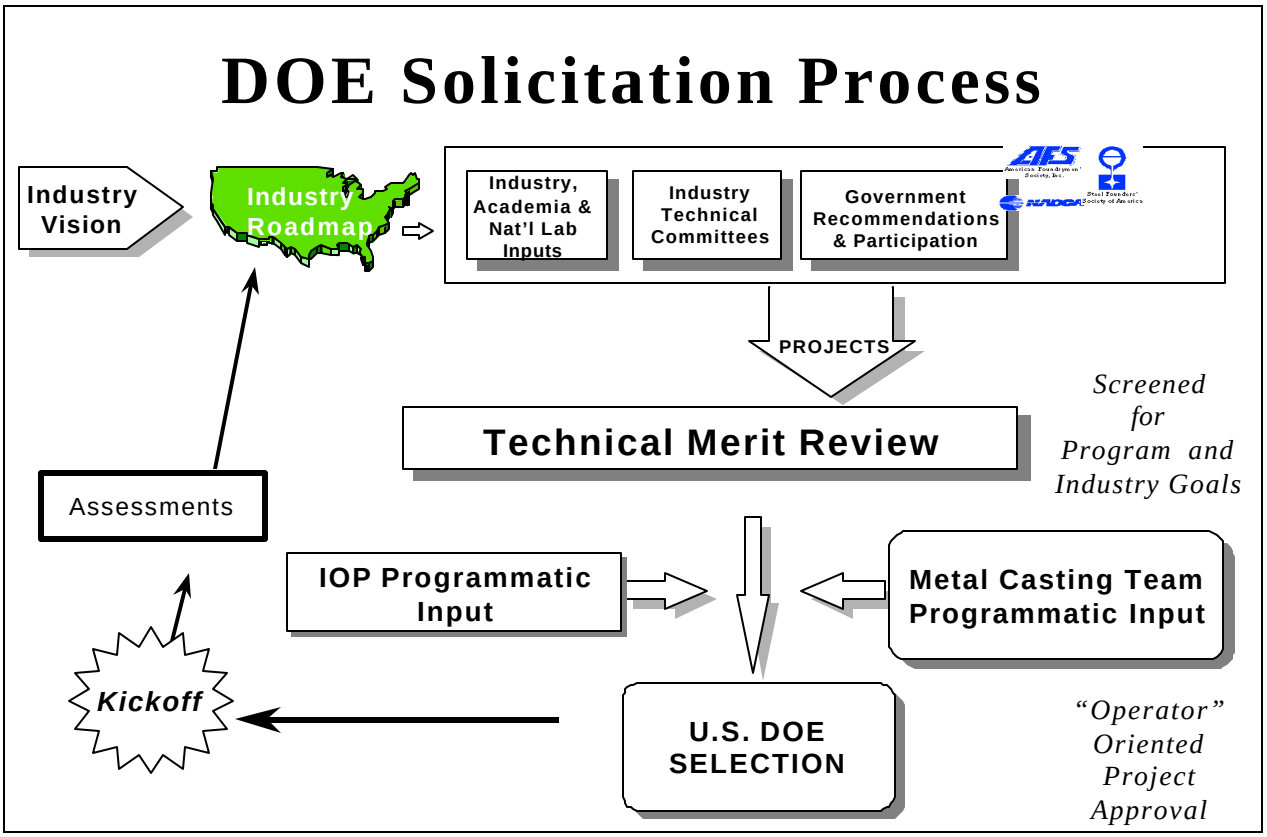
Competitive Solicitations For Metal Casting Research

All research solicitations through the OIT Metal Casting Industry of the Future are open and competitive. The solicitation and proposal review process is illustrated in Exhibit A-2. Solicitations are announced in trade society publications and meetings, the *Commerce Business Daily*, the OIT website and industry websites. DOE receives ad hoc and independent input from industry experts who are members of an Industrial Oversight Panel. The Metal Casting Team of DOE staff also provides independent input on proposals at this stage. Final review and selection is performed by the DOE source selection official.

Collaborations among industry, universities, and national laboratories are encouraged. All research proposals require cost-share. This commitment from industry helps to ensure industry involvement and that the research is aligned with industry's research priorities.

In emphasizing the importance of university-based research, the Program is helping to further the industry goal of enhancing education in the metal casting field of science and in building the human resources that the industry needs in the 21st Century.

Exhibit A-2



Appendix B
Current Metal Casting Research Partners By State

Appendix B
Current Metal Casting Research Partners By State

Bold italics denotes project lead

Alabama
ABC Coke, Birmingham
ABC-NACO, Calera
Alexander City Casting, Alexander
American Cast Iron Pipe Co., Birmingham
Auburn University, Auburn
Citation Corp., Birmingham
Foseco-Morval, Bessemer
Mueller Corporation, Albertville
Southern Alloys, Sylacuagu
University of Alabama, Tuscaloosa
University of Alabama - Birmingham, Birmingham
Vulcan Engineering, Helena

Arkansas
Sloan Valve Company, Augusta

California
ABI, Oakland
Alloy Tool Steel, Santa Fe Springs
Pacific Steel Casting Company, Berkeley

Colorado
Colorado School of Mines, Golden
Colorado State University, Fort Collins

Delaware
Lanxide, Newark

Georgia
Georgia Iron Works, Grovetown
Whitehead Die Casting, Gainesville

Iowa
Iowa State University, Ames
Keokuk Steel Casting, Keokuk
Sivyer Steel Corporation, Bettendorf
University of Iowa, Iowa City

Idaho
Idaho National Engineering and Environmental Laboratory, Idaho Falls

Illinois
A. Finkl & Sons Co., Chicago
ABC-NACO, Downers Grove
ABC-NACO, Cicero
ABC-NACO, Lombard
AECCO, Champaign
Alloy Rods, Champaign
American Foundry Society, Des Plaines (CMC Member)
American Steel Foundries, Granite City
American Steel Foundries, East Chicago
Arrow Aluminum Castings Co. Inc., Woodstock
Austin Associates, Quincy
Brass and Bronze Ingot Manufacturers, Chicago
Catepillar, Inc, Mapleton
Catepillar, Inc., Peoria
Chicago White Metal, Basenville
CMI Novacast, Inc., Elk Grove Village
CMM Services, Morton
FPM Heat Treatment, Elk Grove
General Kinematics, Barrington
H. Kramer & Co., Chicago
Heick Die Casting Corp., Chicago
Illinois Cast Metals Association, North Pekin
Ingersoll Cutting Tools, Rockford
K&P Agile, Naperville
Kirit Dave (consultant), Naperville
MAGMA Foundry Technologies, Arlington Heights
Miller & Co., Rosemont
National Castings, Cicero
North American Die Casting Association, Rosemont (CMC Member)
Primecast, South Beloit
Q.I.T. America, Chicago
R&S Design, Bloomingdale
R. Lavin and Sons, Chicago
Rio Tinto Iron & Titanium, Rosemont
Spartan Light Metal Products, Sparta
Steel Founders' Society of America, Barrington (CMC Member)
Superior Graphite, Chicago
U.S. Environmental Protection Agency, Chicago
Wagner Castings Company, Decatur
Wells Manufacturing, Woodstock

Indiana
ABC-NACO, Anderson
Auburn Foundry, Auburn
Bohn Aluminum Corporation, Butler
Bosch Braking Systems, South Bend
Bremen Castings, Bremen
Cummins Engine, Columbus
Daimler-Chrysler Corporation, Indianapolis
Dalton Kendallville, Kendallville
Dalton Warsaw, Warsaw
Delaware Machinery, Muncie
Electric Steel Castings Company, Indianapolis
GM Powertrain Bedford, Bedford
Hard Chrome, Evansville

Harrison Steel Castings Company, Attica
Hiler Industries, LaPorte
Indiana Cast Metals Association, Indianapolis
Intat Precision, Rushville
Maco Corp, Huntington
Matrix Technologies, Muncie
Ryobi Die Casting (USA), Inc., Shelbyville
Shenango, Terre Haute
Technalysis, Indianapolis
Tri-State University, Angola
Wabash Alloys, Wabash

Kansas

Atchison Casting Corporation, Atchison

Kentucky

Carrollton Casting Center, Carrollton
Furness-Newburge, Inc., Versailles

Louisiana

Carbo Ceramics, Iberia
Hendrix Manufacturing, Mansfield

Massachusetts

Cambridge Tool and Manufacturing Company, North Billerica
EO Associates, Mill River
Kennedy Die Casting, Inc., Worcester
Norton, Worcester
Palmer Foundry, Palmer
Wollaston Alloys, Inc., Braintree
Worcester Polytechnic Institute, Aluminum Casting Research Laboratory Consortium, Worcester
Wyman Gordon Investment Castings, North Grafton

Maryland

Black and Decker, Baltimore
UES, Inc., Annapolis

Michigan

A-CMI, Fruitport
AMCAST Automotive, Southfield
Applied Process Technologies, Livona
Arvin Meritor Automotive, Troy
Bay Cast, Inc., Bay City
Chem-Trend , Howell
Climax Research Services, Farmington Hills
CMI-Michigan Casting Center, Cadillac
Dock Foundry, Three Rivers
EKK, Walled Lake
Ford Electronics Division, Dearborn
Ford Motor Company, Dearborn
Ford Rawsonville Plant, Ypsilanti
Foundry Association of Michigan, Lansing
GM Advanced Development Laboratory, Saginaw
GM Powertrain, Saginaw
GM Powertrain, Pontiac
GM Powertrain Ypsilanti, Ypsilanti
GM Worldwide Facilities Group, Detroit
Grand Rapid Aluminum Casting, Grand Rapids
Hayes-Lemmerz International, Ferndale
Hickman Williams, Livonia
Howmet Corp., Whitehall
ITT Industries, Auburn Hills
LECO, St. Joseph
Metalloy Corporation, Hudson
NEMAK, Southfield
Premier Tool & Die Cast Corporation, Berrien Springs
Prince Machine Co., Holland
Simpson Technologies, Jackson
SIMTEC, Inc, Grand Rapids
SPX Contech Division, Portage
Thixomat, Ann Arbor
TRW Automotive, Livonia
UBE Machinery, Ann Arbor
University of Michigan, Ann Arbor
West Michigan Steel Foundry, Mukegon
XPS Cortech, Portage
Zoller, Ann Arbor

Minnesota

Buhler, Inc., Minneapolis
Hitchcock Industries, Minneapolis
Nicollet, Minneapolis
Progress Casting Group, Plymouth
Superior Industries International, Morris
Tool Products, Minneapolis
United Machine and Foundry, Winona

Missouri

Carondelet Corporation, Pevely
Die Makers, Monroe City
Hubbel Power Systems, Centralia
Missouri Steel Castings, Joplin
Monet Metals, Monett
St. Louis Precision Casting Co., St. Louis
Stahl Specialty Company, Kingsville
University of Missouri - Rolla, Rolla
Wellsville Fire Brick Co., Wellsville

Mississippi

Mississippi State University, Mississippi State
Southern Cast Products, Meridian

New Hampshire

Watts Industries, Franklin

New Jersey

Howmedica Inc., Rutherford
Metallurg Aluminum, Newfield

New Mexico

Arena, LLC, Albuquerque
Flow Science Inc., Los Alamos
Los Alamos National Laboratory, Los Alamos

New York

Copper Development Association, New York
Crucible Steel, Syracuse
Eastern Alloys, Maybrook
International Copper Association, New York
Welding Research Council, New York

North Carolina

Consolidated Diesel, Whitakers
International Lead Zinc Research Organization, Research Triangle Park
Selee Corporation, Hendersonville
Southeastern Foundry Products, Greensboro
University of North Carolina- Charlotte, Charlotte

Ohio

ACM Coldwater, Coldwater
Alotech, Cleveland
Amcast Industrial Corporation, Dayton
A-Mold, Mason
Arrow Aluminum Castings, Avon Lake
Ashland Chemical Co., Cuyahoga Heights
Blaze Technical Sensors, Stow
Borden Chemical, Inc., Toledo
Brost Foundry Co., Cleveland
Brush Wellman, Cleveland
Buckeye Steel Casting, Columbus
Case Western Reserve University, Cleveland
Copeland Corp., Sidney
CSM Industries, Cleveland
DCD Technologies, Cleveland
Edison Materials Technology Center, Dayton
Electroalloys Corp., Elyria
Elkam Metals Co., Ashtabula
Euclid Heat Treat, Cleveland
Fairmont Minerals, Chardon
Foseco, Cleveland
General Die Casters, Peninsula
Global Metal Technologies Inc., Solon
Humtown Products, Columbiana
ITT Automotive, Cleveland
Kowalski Heat Treating, Cleveland
Kurtz Brothers Inc., Groveport
Lester Precision Die Casting, Twinsburg
Lindberg Heat Treat, Solon
Mercury Marine, Solon
Ohio Cast Metals Association, Columbus
Ohio State University, Columbus
Precision Metalsmiths, Inc., Cleveland
Procast, Dayton
Ross Aluminum Foundries, Sidney
Sawbrook Steel Castings Co., Lockland
Thyssen, Cleveland
United Foundries, Canton
Visi-Trak Corp, Cleveland
Wahl Refractories, Fremont
Willard Industries, Cincinnati
ZMD Mold and Die, Mentor

Oregon

Albany Research Center, Albany
Columbia Steel Castings, Portland
Consolidated Metco, Clackamas
Northwest Aluminum Company, The Dalles
PED Manufacturing Ltd., Oregon City
Varicast, Portland

Pennsylvania

Advanced Cast Products, Meadville
Alcan, Pittsburgh
Alcoa, Alcoa Technical Center
Baker Refractories, York
Blue Ridge Pressure Castings, Lehighton
Durametal Corp., Muncy
Erie Bronze & Aluminum, Erie
Esab Welding & Cutting Products, Hanover
Frog Switch Company, Carlisle
Heraeus Electro-Nite Company, Philadelphia
Kennametal, Latrobe
Latrobe Steel, Latrobe
McConway & Torley Corporation, Pittsburgh
North American Refractories, State College
Nova Precision, Auburn
Pennsylvania Foundry Group, Myerstown
Pennsylvania Foundrymen's Association, Plymouth Meeting
Pennsylvania State University, University Park
Pennsylvania Steel, Hamburg
PIAD Precision Casting Corporation, Greensburg
Process Recovery Corp., Sinking Spring
Quaker Alloy, Myerstown
VAW, Inc. , Pittsburgh

South Carolina

Advanced Technology Institute/Cast Metals Coalition, Charleston
Sulzer Pumps, Easley

Tennessee

AEMP Corporation, Jackson
American Magotteaux Intl., Pulaski
MINCO, Inc., Midway
Oak Ridge National Laboratory, Oak Ridge
Saturn Corporation (GM), Spring Hill
Teksid Aluminum Foundry, Inc., Dickson
TTE Die Casting, Oak Ridge
University of Tennessee, Knoxville
Wheland Foundry, Chattanooga

Texas

GH Hensley Industries, Inc., Dallas
KO Steel Foundry, San Antonio
Southwest Steel Castings, Longview
Styrochem Intl., Ft. Worth
Texaloy Foundry, Floresville
Texas Steel, Fort Worth

Utah
Maca Supply, Springville

Virginia
Intermet Technical Service, Lynchburg

Washington
Atlas Foundry and Machine, Tacoma
Kaiser Aluminum and Chemical, Spokane
Spokane Steel Foundry, Spokane
Varicast, Vancouver

Wisconsin
Albany Chicago Company, Kenosha
American Colloid, Berlin
Badger Metal Technology, Menomonee Falls
Badger Mining, Berlin
Bay Engineered Castings, De Pere
Briggs & Stratton, Milwaukee
Briggs & Stratton, West Allis
Briggs Die Casting, Wauwatosa
Brillion Iron Works, Brillion
Eck Industries, Manitowock
Falk Corporation, Milwaukee
Grede Foundries, Inc., Reedsburg
Harley-Davidson Motor Company, Milwaukee
IMA USA, Inc., Sheboygan
International Truck and Engine Corp, Waukesha
JL French Corporation, Sheboygan
Kohler Company, Kohler
Madison-Kipp Corp., Madison
Maynard Steel Casting, Milwaukee
Mercury Marine, Fond Du Lac
Milwaukee Steel, Milwaukee
Neenah Foundry Company, Neenah
Outboard Marine Corp., Waukesha
Payne and Dolan, Inc, Waukesha
Pelton Casteel, Milwaukee
Stainless Foundry & Machine, Milwaukee
Starline Manufacturing Co, Inc., Milwaukee
University of Wisconsin, Madison
University of Wisconsin - Milwaukee, Milwaukee
Walkington Engineering, Cottage Grove
Waukesha Cherry Burrell, Delavan
Waupaca Foundry Co, Waupaca
Wisconsin Cast Metals Association, Milwaukee
Wisconsin Centrifugal, Inc., Waukesha
Wisconsin Invest Cast, Watertown
Wright Products Corp., Rice Lake

West Virginia
Ormet Corporation Wheeling

Appendix C

Current Metal Casting Research Projects and Partners: By Roadmap Area

Appendix C
Current Metal Casting Research Projects and Partners: By Roadmap Area

Manufacturing Technologies

Advanced Lost Foam Process, University of Alabama - Birmingham - Lost Foam Casting has significant cost and environmental advantages and enables metal casters to produce complex parts. It allows designers to consolidate parts, reduce machining and minimize assembly operations. It also allows foundries to reduce solid waste and emissions. Research has resulted in significant improvements in lost foam process controls. The current goal is to develop a database for pattern degradation properties at typical metal velocities and temperatures. This data, along with coating and sand permeability and thermal property data, will be merged into a commercial fill/solidification code to describe the physical events of metal replacement of lost foam patterns and validated using real time x-ray and instrumented castings. In-plant experiments will quantify sources of casting distortion and to demonstrate the validity of existing compaction theory and sand thermal expansion theory. Procedures will be developed to measure pattern /bead properties that control the bead pre-expansion and pattern blowing process. New pattern materials that produce less liquid and/or carbon degradation products will be investigated. Coating quality control procedures will be developed with more robust techniques.

University of Missouri - Rolla, Rolla, MO
American Foundry Society, Des Plaines, IL
Advanced Cast Products, Inc., Meadville, PA
Alex City Casting, Alexander, AL
Ashland Chemical Co., Cuyahoga Heights, OH
Austin Associates, Quincy, IL
BMW AG, Landshu, Germany
Borden, Inc., Toledo, OH
Carbo Ceramics, Iberia, LA
Citation Corp., Birmingham, AL
Copeland Corp., Sidney, OH
Delaware Machine, Muncie, IN
Flow Science, Los Alamos, NM
Foseco-Morval Inc., Cleveland, OH
General Kinematics Corp., Barrington, IL
General Motors, Bedford, IN
Kohler Company, Kohler, WI
Kurtz North America, Groveport, OH
Maco Corp., Huntington, IN
Mercury Marine, Fond du Lac, WI
Mueller Corp., Albertville, AL
Nemak, Southfield, MI
Outboard Marin Corp., Waukesha, WI
Saturn Corp., Spring Hill, TN
Southeastern Foundry Products Greensboro, NC
Styrochem International, Ft. Worth, TX
UES Inc., Annapolis, MD
Vulcan Engineering, Helena, AL
Willard Industries, Cincinnatti, OH

Clean Metal Casting, Worcester Polytechnic Institute - The objective of this project is to develop a technology for clean metal processing that is capable of consistently providing a metal cleanliness level fit for a particular application. The emphasis will be on non-ferrous metals, particularly aluminum casting alloys. Two classes of contaminants that prevail in molten aluminum are being studied: hydrogen and inclusions (oxides, carbides, etc.). methods to control process atmosphere using inert and reactive gases to reduce hydrogen absorption are being investigated. Alloying elements and supernatant cover media that may substantially reduce melt oxidation are also being considered. Barrier coatings that interfere with in situ carbide formation are being researched.

American Foundry Society, Des Plaines, IL
FOSECO, Cleveland, OH
Hitchcock Industries, Minneapolis, MN
Kennedy Die Castings, Inc., Worcester, MA
Madison-Kipp Corp., Madison, WI
Palmer Foundry, Palmer, MA
Selee Corporation, Hendersonville, NC
Stahl Specialty Company, Kingsville, MO

Clean Cast Steel, University of Alabama - Birmingham - The objective of this research is to reduce scrap and improve casting product quality by removing or minimizing oxide defects. It will focus on the metallurgical factors influencing machinability of steel and to gain an engineering understanding of the mechanism. In past years, research efforts were concentrated on macro-inclusion that break, chip or crack machine tool cutters and drills and cause productivity losses. Work to eliminate these led to optimizing pouring techniques including metal stream shrouding and ladle design, and evaluating in-mold devices such as filters and filter-flow control devices for their ability to reduce macro-inclusions. Current work applies a computer model to simulate metal flows and identify the effects of flow conditions on casting quality. Methods of homogenizing the metal temperature in the ladle will also be evaluated. Research is also being conducted to determine sources of heat-to-heat variations in metal cleanliness. Foundry trials demonstrated that modifications of the furnace practice can improve the quality of steel castings.

Steel Founders' Society of America, Barrington, IL
American Magotteaux, laski, TN
American Steel Foundries, anite City, IL
Atchison Casting Corp., Atchison, KS
Dominion Castings Ltd., Ontario
Electric Steel Castings, Indianapolis, IN
Falk Corporation, Milwaukee, WI
Harrison Steel Castings, Attica, IN
Keokuk Steel Castings, Inc., Keokuk, IA
Maynard Steel Castings, Milwaukee, WI
National Castings, Cicero, IL
Sawbrook Steel Casting, Lockland, OH
Selee Corporation, Hendersonville, NC
Stainless Foundry & Engineering, Milwaukee, WI
Wisconsin Centrifugal, Milwaukee, WI

Computer Modeling the Mechanical Performance of Die Casting Dies, Ohio State University - The majority of die casting computer modeling work focuses on thermal or filling issues including solidification. Although the simulation of mechanical and thermal load effects is critical for high pressure die casting and for squeeze casting it is not yet addressed by commercial casting design packages. In an attempt to resolve this, stress analysis packages for the casting are beginning to be used, but they are based on the nominal part geometry (as defined by the CAD model) and not the actual part shape at ejection. This is not a reasonable assumption for die casting. Due to the clamping and operating pressure involved, the mechanical performance of the die and machine must be considered in order to better understand the part ejection conditions. This project will further advance the state of the art in computer modeling and simulation to solve die casting design problems in practical ways. Relationships among the design variables will be determined, and a design methodology will be established. This will lead to a better understanding of how to design dies to meet clamping, thermal, and pressure loads. By incorporating design methods and computer modeling in the design phase, this project will reduce the number of test-rework-repair iterations necessary to put a new die into service.

North American Die Casting Association Rosemont, IL	*GM Bedford, Bedford, IN*	*Visi-Trak Corporation, Cleveland, OH*
Briggs & Stratton, Milwaukee, WI	*Lester Precision Die Casting, Twinsburg, OH*	*Walkington Engineering, Cottage Grove, WI*

Computer Modeling of Shot Sleeves, Ohio State University - During the first phase of this project, a variety of shot sleeves in commercial use were evaluated using two and three dimensional finite element models. Also, a shot sleeve test stand was constructed to experimentally determine appropriate heat transfer coefficients for the finite element models. Actual sleeve distortions have also been measured using the test stand. The fundamental objective of the proposed research is to understand the effect of casting rate, alloy temperature, type and amount of shot sleeve lubricant, shot sleeve design, and shot sleeve materials on thermally induced shot sleeve distortion. Shot sleeve distortion causes the injection cycle to be interrupted because the plunger tip binds and sticks in the sleeve. This causes excessive wear of the sleeve and tip, increased scrap generation because the proper injection velocities can not be achieved, and cycle time interruptions due to the plunger tip sticking in the sleeve upon ejection of the biscuit. The technical result of improved shot sleeve design and useful life translates into less die casting machine downtime, lower tooling costs, and improved casting quality. This will also reduce energy required per acceptable casting produced.

Briggs & Stratton, Milwaukee, WI	*Lester Precision Die Casting, Twinsburg, OH*	*Walkington Engineering, Cottage Grove, WI*
GM Bedford, Bedford, IN	*Visi-Trak Corp, Cleveland, OH*	*XPS Cortech, Portage, MI*

Development of Computational Fluid Dynamics Tool for Modeling the Blowing and Steaming of EPS Patterns for Lost Foam Casting, Arena, LLC - The lost foam casting process produces clean, high quality castings with close tolerances. The most important advantage is that no cores (with binders) are required. One challenge in lost foam casting is maintaining the uniformity and quality of the expandable polystyrene (EPS) pattern. This has often been the cause of defects in casting. It is estimated that 60% of lost foam defects can be attributed to the pattern, or the so-called “white-side.” Foam molds are complex and beads must flow through complex passages to completely fill the mold. The process is further complicated by the expansion of the beads. In this project, Flow Simulation Sciences in conjunction with the American Foundry Society and the metal casting industry will extend existing flow modeling software to simulate the air-driven blowing of pre-expanded beads into a mold, and the subsequent steaming (expansion) of beads as they form a lost foam pattern. They will develop a CFD Tool for improving design and development of expandable polystyrene patterns for lost foam castings.

American Foundry Society, Des Plaines, IL	*GM Advanced Development Lab, Saginaw, MI*	*StyroChem, Ft. Worth, TX*
Auburn University, Auburn, AL	*Mercury Marine, Fond Du Lac, WI*	*Vulcan Engineering, Helena, AL*

Development of Surface Engineered Coatings for Die Casting Dies, Colorado School of Mines - The objective of this project is to develop an optimal "coating system" that minimizes the major mechanisms leading to premature die failure. These mechanisms include: heat checking (thermal cracking), and gross cracking; erosive wear; and soldering and corrosion/oxidation. Ultimately, the goals of this research program are: 1) the achievement of increased die-casting die life; 2) increased surface quality of die-cast components; 3) decreased downtime during scheduled production; 4) increased substitution of aluminum die-cast components for steel and cast iron; and 5) decreased in-process (pre-consumer) scrap. The measured outcomes from this research will quantify comparisons of the current aluminum die-casting practice with the measured results using the newly developed coating systems. A comparison of cost/performance will also be determined for the new coating systems using current cost data as the base line.

North American Die Casting Association Rosemont, IL	*Hard Chrome, Evansville, IN*	*SPX Contech, Portage, MI*
Blue Ridge Pressure Castings, Lehighton, PA	*Hayes-Lemmerz, Ferndale, MI*	

Die Deflection Modeling and Technology Transfer, Ohio State University - The overall goal of this project is to gather knowledge and develop methods which can be applied to design better running dies that will reduce the number of test and rework iterations necessary to put a new die in service. Better running dies will produce more consistent parts with less scrap, wasted operations, and wasted energy. Such work is essential since the users of die castings continue to demand higher and higher quality parts produced with much shorter product development lead times. The project will develop and apply additional empirical data for validation of the models and conclusions resulting from current studies. Additionally, the project will test new design guidelines in the field and develop case studies for technical transfer purposes.

DCD Technologies, Cleveland, OH

Delaware Machinery, Muncie, IN

EKK, Walled Lake, MI

EXCO Engineering, New Market, Ontario

Ford Electronics Division, Dearborn, MI

Ford - Rawsonville Plant, Ypsilanti, MI

General Die Casters, Inc., Peninsula, OH

General Motors Powertrain, Bedford, IN

JL French Corporation, Sheboygan, WI

MAGMA Foundry Technologies, Inc., Arlington Heights, IL

Matrix Technologies, Muncie, IN

Prince Machine Corporation, Holland, MI

Ryobi Die Casting (USA), Inc., Shelbyville, IN

Tool Products, Minneapolis, MN

Walkington Engineering, Cottage Grove, WI

Wright Products Corp., Rice Lake, WI

Die Materials for Critical Applications and Increased Production Rates, Case Western Reserve University - The objective of this project is to double the life of die casting inserts exposed to the most severe die casting conditions by testing, comparing, and providing guidelines for selective use of: (a) high-alloy tool steels, (b) refractory and other nonferrous high temperature die materials, and (c) diffusion coatings. Prior work conducted by Case Western Reserve demonstrated that dies produced from chromium-molybdenum-vanadium steels with about 0.40% carbon and a minimum of inclusions and segregation and heat treated to a Rockwell C range of 45-50 provide good thermal fatigue resistance. With appropriate composition and quality of these steels, optimized austenitizing temperature and fast cooling rate, these studies show that improved die life can be expected in most applications. However, under certain circumstances and specific locations, these good quality tool steels are prone to early failure. The use of special materials for inserts or cores can extend the die life in severe conditions. Researchers will study the behavior of these materials from a basic microstructure standpoint and evaluate the relative behavior of candidate materials.

A. Finkl & Sons, Chicago, IL

Alloy Tool Steel, Santa Fe Springs, CA

Badger Metal Technology, Menomonee Falls, WI

Brush Wellman, Cleveland, OH

Chem-Trend, Howell, MI

CMI-Tech Center, Ferndale, MI

CSM Industries, Cleveland, OH

DCD Technology, Cleveland, OH

FPM Heat Treatment, Elk Grove, IL

Latrobe Steel, Latrobe, PA

Effects of Applied Pressure During Feeding on the Fatigue Properties of Critical Cast Aluminum Alloy Components, Mississippi State University - Recently, there has been a renewed interest in a feeding technique capable of minimizing this porosity. The techniques involves a highly localized pressurization of the feed metal within the risers of the casting. The method leads to improved mechanical properties, increased casting yield, reduced energy use and environmental impact. This research is to determine the effect of applied pressure during feeding on the distribution, level, and morphology of porosity, and subsequently on the fatigue behavior of critical cast aluminum components. Many components used in safety-critical systems in automobiles and aircrafts, are of complex shape and lend themselves to casting to minimize costs. Many of the alloys used in these applications freeze over a long temperature range and are prone to dispersed porosity defects. Dispersed porosity in aluminum alloy castings has profound effects upon mechanical properties of engineered components produced this way. Both static properties (ductility, tensile strength, etc.) and dynamic properties (fatigue strength, and properties associated with the time dependence of fatigue crack initiation and growth) are affected. Although rigorous techniques of degassing and riser design can partly alleviate this situation, the effects of residual porosity are serious.

A-CMI, Michigan Casting Center Fruitport, MI

Bohn Aluminum Corporation, Butler, IN

cmi novacast, inc., Elk Grove Village, IL

Ford Motor Company, Dearborn, MI

Foseco, Cleveland, OH

GM Powertrain, Pontiac, MI

The Metalloy Corporation, Hudson, MI

Effects of Die Design & Dimensional Features on Thermal Fatigue Cracking of Die Casting Dies, Case Western Reserve University - The goal of this research is to identify and evaluate the effect of design factors such as size and location of cooling lines, sudden changes in cross-section and sharp radii on the life of die casting dies. The study will provide die designers with computer tools that allow them to predict the thermal stresses in dies and a method to relate these stresses with thermal fatigue cracking. These tools can be applied towards mitigating or eliminating design related problems and their adverse effect on die life. The study will develop a new approach in design of dies for thermal fatigue resistance. This approach is designed to identify potential hot spots (thermal) and high stresses in the design by minimizing them by modifying the dimensions of the inserts and the location and size of the cooling lines. It includes 1) computer aided design of the die with all geometrical details, including location of cooling lines, 2) couple finite element modeling of flow/thermal/stress of the die, and 3) thermal fatigue immersion testing to determine the actual effect of the maximum design temperatures and stresses on the heat checking damage.

North American Die Casting Association Rosemont, IL
A. Finkle & Sons, Chicago, IL
Alloy Tool Steel, Santa Fe Springs, CA
Brush Wellman, Cleveland, OH
Badger Metal Technology, Menomonee Falls, WI
Latrobe Steel Company, Latrobe, PA
Lester Precision Die Casting, Twinsburg, OH
Chem-Trend, Howell, MI
CSM Industries, Cleveland, OH
DCD Technologies, Cleveland, OH
FPM Heat Treatment, Chicago, IL
General Die Casters, Peninsula, OH
Hayes-Tech Center, Ferndale, MI
Procast, Dayton, OH

Gating of Aluminum Permanent Mold Castings, Case Western Reserve University - The objective of the project is to provide a basis for improved gating design for vertically-parted aluminum permanent mold castings. The design of gating for conventional gravity-fed vertically-parted permanent mold castings is a task which is performed daily throughout the foundry industry, but for which there is a great deal of dissatisfaction with the current design methodology and recommended gating designs. Basic gating design has remained essentially unchanged since the mid 1950's. This program will examine the gating of vertically-parted aluminum permanent mold castings through a combination of experiments and computer simulations to develop improved gating designs. The improved gating systems will aim to eliminate molten metal surface turbulence during mold filling in order to reduce casting defects, maximize thermal gradients during solidification to aid metal feeding, provide necessary risers as a source of feed metal, and maximize casting yield by minimizing gating and riser size. Through improved gating design, castings can be produced with higher casting yields, lower scrap rates, lower defect contents, and with fewer initial design iterations.

Amcast Automotive, Southfield, MI
American Foundry Society, Des Plaines, IL
Arrow Aluminum Castings, Avon Lake, OH
Bohn Aluminum, Butler, IN
CMI-Michigan Casting Center. Cadillac, MI
DCD Technologies, Cleveland, OH
Foseco, Cleveland, OH
Grand Rapid Aluminum Casting, Grand Rapids, MI
Hayes-Lemmerz, Ferndale, MI
Stahl Specialty Co., Kingsville, MO
St. Louis Precision Casting, St. Louis, MO
UES, Annapolis, MD

Heat Transfer at the Mold/Metal Interface in Permanent Mold Casting of Aluminum Alloys, University of Michigan - The objective of this project is to evaluate heat transfer between mold and casting in permanent casting of aluminum alloys. Considerable energy savings can be achieved by more precise design of these castings. The design improvements require further understanding of the fundamentals of the process, in particular, interfacial heat transfer including the influence of gap formation and mold coatings, the stress and deformation of the solidifying castings, as well as the thermal and mechanical behavior of the mold. This research program will include modeling and experimental measurements of the parameters with the objective to provide a means for the foundry worker to define and predict multidimensional heat flow in permanent mold casting. The resulting design will allow production of castings with closer tolerances, improved properties, higher integrity, and lower weight.

American Foundry Society, Des Plaines, IL
AMCAST Automotive, Southfield, MI
Hayes Lemmerz Tech Center, Ferndale, MI
Magma Foundry Technologies, Inc., Arlington Heights, IL
UES, Inc., Annapolis, MD

Improvements in Sand/Mold/Core Technology and Effects on Casting Finish, Ohio State University - The goal of this project is to improve casting surface finish in sand mold/core technology. Specifically, it will develop a predictive understanding of how density variations control sand structure and casting surface finish and to identify when and how this results in severe penetration. In addition, it will develop a predictive understanding of how binder content and mixing controls both density variations and surface finish. This research also will analyze the behavior of manufactured binders and binder additives at the mold-metal interface. X-ray Computed Tomography is required to separate the performance of these organics from the effects of density variations.

American Foundry Society, Des Plaines, IL	*The Edison Materials Technology Center, (EMTEC), Dayton, OH*	*Ross Aluminum Foundries, Sidney, OH*
Alotech, Cleveland, OH		*Watts Industries, Inc., Franklin, NH*
Amcast Industrial Corporation, Dayton, OH	*Humtown Products, Columbiana, OH*	

Integration of RSP Tooling with Rapid Prototyping for Die Casting Applications, Colorado State University - Die casting can quickly produce intricate, high quality metal components in high volume. However, die casting dies continue to be manufactured through the use of machining practices, materials, and heat treatment practices developed many years ago. In this project, a new and unique Rapid Solidification Process (RSP) technology will be introduced to the die casting industry that will reduce lead time for prototyping and producing die casting tooling. In addition to productivity increase, use of RSP Tooling technology will also result in a substantial reduction in energy use and scrap than conventional machining practices.

North American Die Casting Association Rosemont, IL	*Global Metal Technologies, Inc., Solon, OH*	*Idaho National Engineering and Environmental Laboratory, Idaho Falls, ID*

Investment Shell Cracking, Tri-State University - This project will investigate methods to produce more reliable mold shell for investment casting. Recent developments in materials testing for structural ceramics and polymers will be adapted to ceramic shells and wax patterns used in investment casting. The project will include: 1) designing a standard test casting, 2) developing bench-scale tests for ceramic shells and wax (polymer) pattern materials, (3) applying these tests to production materials from participating foundry companies and correlating the results with observed defect occurrences, and 4) determining which process parameters can be used that most directly correlate with the results from bench-scale and participating foundries.

Steel Founders' Society of America, Barrington, IL	*PED Manufacturing, Oregon City, OR*	*Wisconsin Centrifugal, Waukesha, WI*
ABC-NACO, Cicero, IL	*Stainless Foundry, Milwaukee, WI*	*Wisconsin Invest Cast, Watertown, WI*
Nova Precision, Auburn, PA	*Spokane Steel, Spokane, WA*	

Mold Materials for Permanent Molding of Aluminum Alloys, Case Western Reserve University - The primary goals of this project are to extend the life and improve the quality of permanent molds utilized in casting aluminum. At present, the metal molds used in permanent molding of aluminum alloys are selected from a fairly large field of materials ranging from gray iron to high strength tool steels. Mold life varies significantly, affecting the cost of the products. The usual mode of failure of permanent molds for aluminum casting is thermal fatigue cracking produced by the cyclic thermal stress on the mold face. Resistance to thermal fatigue can be increased by using mold materials that have a combination of high thermal conductivity, high strength at elevated temperature, low coefficient of thermal expansion and a low modulus of elasticity. The primary goals of this project are to extend the life and improve the quality of permanent molds utilized in casting aluminum. The relative mold life under the thermal conditions that prevail in permanent molds that experience exposure to molten aluminum will be determined for a range of materials such as gray iron (Meehanite), ductile iron, and compacted graphite iron. Other candidate materials are cast and wrought 4140 type steels, and cast and wrought H-13 steels. An additional goal is to reduce the cost of the molds and improve the surface and soundness quality of the aluminum castings by selective application of coatings.

American Foundry Society, Des Plaines, IL	*DCD Technology, Cleveland, OH*	*Progress Casting Group, Plymouth, MN*
Amcast Automotive, Southfield, MI	*Foseco, Inc., Cleveland, OH*	*Stahl Specialty Company, Kingsville, MO*
Arrow Aluminum Casting, Woodstock, IL	*Grand Rapid Aluminum Casting, Grand Rapids, MI*	*St. Louis Precision Castings, St. Louis, MO*
Bohn Aluminum Corporation, Butler, IN	*Hayes Lemmerz-CMI, Ferndale, MI*	*UES, Inc., Annapolis, MD*

Optimization of Composition and Heat Treating of Die Steels for Extended Lifetime, Case Western Reserve University - The objective of this study is to obtain a 50% improvement in the life of die casting dies by compositional modifications and optimized heat treatment. Previous efforts have been successful, resulting in the finding of a new type of die steel with al lower silicon and vanadium, and higher molybdenum content than the standard premium grade H-13 steel. Further improvement in the life of the die steels can be obtained by utilizing a rapid cooling rate from a slightly higher austentizing temperature during the hardening process.

North American Die Casting Association Rosemont, IL	*Badger Metal Technology, Menomonee Falls, WI*	*FPM Heat Treatment, Elk Grove Village, IL*
	Chem-Trend, Howell, MI	*Hayes/CMI Tech, Ferndale, MI*
Alloy Tool Steel, Santa Fe Springs, CA		
	DCD Technology, Cleveland, OH	*Latrobe Steel Company, Latrobe, PA*

Optimization of Squeeze Casting Process for Aluminum Alloy Parts, Case Western Reserve University - The objective of this project is apply fundamental heat and mass transfer principles to the squeeze casting process to optimize the variables and improve the quality of the castings manufactured by this process. Squeeze casting is a new and developing casting process suitable for manufacturing light-weight structural aluminum castings needed for the production of advanced components in applications such as the automotive industry. Because squeeze casting is a relatively new process, much work needs to be done to better understand the fundamentals of the process in order to optimize the variables. In this project, fundamental heat and mass transfer principles will be applied to the squeeze casting process, with experimental work performed on an industrial-scale 315 metric tonne squeeze caster.

North American Die Casting Association, Rosemont, IL
Blaze Technical Sensors, Stowe, OH
DCD Technologies, Cleveland, OH
Euclid Heat Treat, Cleveland, OH
Ford Motor Company, Dearborn, MI
Hayes-Lemmerz-CMI, Ferndale, MI
ITT Automotive, Cleveland, OH
Latrobe Steel Company, Latrobe, PA
Lindberg Heat Treat, Solon, OH
Nicollet, Minneapolis, MN
UBE Machinery, Ann Arbor, MI

Re-Engineering Casting Production Systems, Iowa State University - Many foundries suffer from poor facility design and large work in process inventories. The problems especially occur in the casting finishing areas, which includes blast cleaning, riser removal, grinding, production welding and heat treatment. The problem is in part due to the labor intensive nature of the finishing processes. Typically, finishing accounts for 50% of the cost of production steel castings. This project aims to decrease the costs of producing castings by improving the production systems used to produce them. The goal of the project is to develop solutions that are applicable to the entire foundry industry, and disseminate the results through technology transfer activities. This project is making improvements in the areas of scheduling, inspection and rework practices, plant layout and material handling.

Steel Founders' Society of America, Barrington, IL
AECCO, Champaign, IL
Atchison Casting, Atchison, KS
American Steel Foundries, East Chicago, IL
Bay Cast, Inc., Bay City, MI
Buckeye Steel Castings, Columbus, OH
Carondelet Corporation, Pevely, MO
Durametal Corporation, Muncy, PA
Erie Bronze & Aluminum, Erie, PA
Falk Corporation, Milwaukee, WI
Harrison Steel Castings Company, Attica, IN
Hendrix Manufacturing, Mansfield, LA
Magotteaux Pulaski, Pulaski, TN
Maynard Steel Casting Co., Milwaukee, WI
McConway & Torley Corporation, Pittsburgh, PA
Monett Metals, Monett, MO
NACO, Lombard, IL
Pacific Steel Casting, Berkeley, CA
Pennsylvania Foundry Group, Myerstown, PA
PrimeCast, South Beloit, IL
Sawbrook Steel Castings Co., Lockland, OH
Sivyer Steel Corporation, Bettendorf, IA
Southern Alloy Corporation, Sylacauga, AL
Southern Cast Products, Meridian, MS
Southwest Steel Castings Co., Longview, TX
Spokane Steel Foundry Co., Spokane, WA
Sulzer Pumps, Easley, SC
Texas Steel Company, Fort Worth, TX
United Machine and Foundry, Winona, MN
Varicast, Inc., Portland, OR
Waukesha, Delavan, WI
West Michigan Steel Foundry, Muskegon, MI
Wisconsin Centrifugal, Waukesha, WI
Wollaston Alloys, Braintree, MA

Sensors for Die Casting*, *Oak Ridge National Laboratory*, *Hayes Lemmerz, Inc. - The goal of this project is to evaluate and implement vibration sensors for machine diagnostics of die casting machines which will improve the quality and consistence of production castings made by the die casting industry. Emphasis will be placed on the application of commercially available sensors, and on their implementation in a robust and practical format that may be readily transferred to the die casting industry. The sensor technologies implemented will allow problems to be detected and solved during the casting cycle, leading to less scrap, improved surface finish, higher dimensional repeatability, and improved internal integrity. Consequently, the technologies can significantly impact the economics of the casting process as well as allow die casters to expand the market for die castings. The technologies implemented may be transferred to other pressure casting processes such as squeeze and semi-solid metal casting.

American Foundry Society, Des Plaines, IL
A-CMI, Michigan Casting Center , Fruitport, MI
Bohn Aluminum Corporation, Butler, IN

Service Performance of Welded Duplex Stainless Steel Castings and Wrought Material, University of Tennessee - Welding can impair the corrosion performance of both wrought and cast materials. The corrosion performance is most egregiously degraded by welding processes, which leave behind a fusion zone containing melted base material. However, a paucity of data exists upon which the specifier/engineer can base service performance. This project is developing a suitable database to provide detailed fabrication and service performance guidelines including welding and heat treatment procedures for duplex stainless steel and wrought materials. The database will enable the industry to reduce wastes resulting from improper fabrication and heat treatment methods, to reduce fabrication time due to undocumented fabrication procedures, and to improve service performance of components fabricated from duplex stainless steels, comparing to conventional materials.

Steel Founders' Society of America, Barrington, IL
Alloy Rods, Champaign, IL
Atlas Foundry and Machine, Tacoma, WA
Keokuk Steel Casting, Keokuk, IA
Quaker Alloy, Myerstown, PA
Stainless Foundry, Milwaukee, WI
Welding Research Council, New York, NY
Wollaston Alloys, Braintree, MA

Thin Wall Iron Castings, University of Alabama - Foundries specializing in automotive castings must develop new processes and materials that reduce overall car weight to meet federally mandated fuel economy standards, without sacrificing performance. Automakers have increasingly turned to lighter weight materials, and castings continue to be a prime target. For cast iron to regain lost markets it must be better engineered to achieve its full potential. At present time, iron castings cannot be routinely produced in sand mold with thickness less than 3 mm. In addressing this need, research is being carried out to develop the technology for producing commercial iron castings with wall thickness less than 3 mm. The objective of this program is to develop the technology to produce commercial castings of gray, ductile, and compacted graphite iron with wall thickness less than 3mm. The project will investigate both the metallurgical treatment required for molten iron, and the mold and core-making techniques.

University of North Carolina - Charlotte Charlotte, NC
American Foundry Society, Des Plaines, IL
ABC Coke, Birmingham, AL
American Colloid, Berlin, WI
Badger Mining, Berlin, WI
Brillion Iron Works, Brillion, WI
Caterpillar, Inc., Mapleton, IL
Carrollton Casting Center, Carrollton, KY
Chrysler Foundry, Indianapolis, IN
Citation Corp., Birmingham, AL
Elkam Metals Co., Ashtabula, OH
Fairmont Minerals, Chardon, OH
Ford Motor Co., Dearborn, MI
Foseco, Inc., Cleveland, OH
Georg Fischer DISA A/S, Denmark
GM Powertrain, Saginaw, MI
Hickman Williams & Co., Livonia, MI
Intat Precision, Rushville, IN
Intermet Technical Service, Lynchburg, VA
K&P Agile, Inc., Naperville, IL
Magma Corp., Arlington Heights, IL
Miller & Co., Rosemont, IL
Rio Tinto Iron & Titanium, Rosemont, IL
Simpson Technologies, Jackson, MI
Superior Graphite, Chicago, IL
UES Software, Annapolis, MD

Ultrahigh Speed Measurement of Internal Die Cavity Temperature Profiles for Process Control and Model Verification, Prince Machine - The goal of this project is to develop and test a device that could image the flow in the interior of a die casting die and, if possible, measure the temperature of the part as it is formed in the die cavity. A reliable prototype system has been demonstrated that will capture the time/temperature profile, internal to a die cavity, at sampling rate up to 100KHz. This system is configured around a production aluminum die casting die that was modified to allow the installation of small diameter cylindrical sapphire windows into the cavity. In order to measure the internal die cavity temperatures, radiation passing through the sapphire windows is monitored by a custom designed, high speed, two color ultra-high-speed infrared pyrometer or a high speed IR camera. Either device can be used to measure the temperature at various locations around the die cavity. Based on the these promising preliminary results, it is expected that continued development of this system will offer new possibilities for process control and modeling experimental verification.

North American Die Casting Association Rosemont, IL
Oak Ridge National Laboratory, Oak Ridge, TN
University of Tennessee, Knoxville, TN
TTE Die Casting, Oak Ridge, TN
Whitehead Die Casting, Gainesville, GA

Understanding the Relationship Between Pattern Filling and Part Quality in Die Casting, Ohio State University - The objective of this project is to understand the phenomena involved in the filling of the die cavity and the relationships between fill parameters and part quality. The affects of gate geometry at part entry, gate velocity, and slow-to-fast shot acceleration on filling patterns in die casting, and ultimately part quality, will be explored. The results should produce a better understanding of the die filling phenomena under a variety of gate entry geometries, selected common cavity geometries, and gate velocities. This work will enable improvements in productivity and quality. Energy and emissions savings arise primarily due to scrap reduction including reductions due to faster startup, less die tryout, and a better understanding of the relationship between fill and part quality. An outcome of the research will be a computer program that would predict die casting quality level given a set of pre-defined gate geometry and processing variables. This will greatly assist industry to improve productivity and reduce lead time.

North American Die Casting Association Rosemont, IL	*GM Bedford, Bedford, IN*	*Walkington Engineering, Cottage Grove, WI*
General Die Casters, Peninsula, OH	*Lester Precision Die Casting, Twinsburg, OH*	

Yield Improvement in Steel Castings, University of Iowa - The objective of the research is to investigate methods for improving yield in steel casting. Specific goals are: to develop techniques to improve yield on current practices by 10% while maintaining the same quality level; develop novel techniques to improve yield by 25% on a fully optimized casting system; and document the developed techniques, procedures and findings in manuals and reports to allow all steel casting producers to benefit. Research is emphasizing 1) Conventional feeding and risering methods, 2) Unconventional yield improvement techniques, and 3) Case studies.

Steel Founders' Society of America Barrington, IL	*Harrison Steel Castings, Attica, IN*	*Quaker Alloy, Myerstown, PA*
American Steel Foundries, Granite City, IL	*KO Steel Foundry, San Antonio, TX*	*Shenango, Terre Haute, IN*
Atchison Casting, Atchison, KS	*Missouri Steel Castings, Joplin, MO*	*Stainless Foundry, Milwaukee, WI*
Bay Cast, Bay City, MI	*NACO, Downers Grove, IL*	*Texas Steel, Fort Worth, TX*
Electric Steel, Indianapolis, IN	*Pacific Steel Casting Company, Berkeley, CA*	*Varicast, Portland, OR*
Falk, Milwaukee, WI	*Pennsylvania Steel, Hamburg, PA*	*Waukesha Cherry-Burell, Delevan, WI*

Materials Technologies

Age Strengthening of Gray Cast Iron Phase III, Tri-State University - This project will identify the age-strengthening mechanism in gray cast iron, quantify the parameters which control the process, measure properties and develop a predictive model, and quality the relationship between aging and machinability. The project includes four main tasks. The time and temperature effect studies will be done in laboratory environment with irons cast at production foundries. The composition will be varied so that the effect of nitrogen activity and activity coefficient can be evaluated as well as the influence of substitutional elements on the process. This will require about five test-bar casting runs per year in participating foundries. This data will allow us to control and design with the process, but will also contribute to the understanding of the process.

American Foundry Society, Des Plaines, IL	*Bremen Castings, Bremen, IN*	*Dock Foundry, Three Rivers, MI*
ACM Coldwater, Coldwater, OH	*Dalton Kendallville, Kendallville, IN*	*LECO, St. Joseph, MI*
Auburn Foundry, Auburn, IN	*Dalton Warsaw, Warsaw, IN*	

Casting Characteristics of Aluminum Die Casting Alloys, Worcester Polytechnic Institute - In this project, WPI will examine the melting and casting characteristics of aluminum die casting alloys. The specific objective of this research is to relate alloy chemistry to critical melting and casting characteristics such as the quantity and type of sludge produced during melting, melt fluidity, the tendency of the alloy to stick to the die components, and the tendency of the alloy to hot tear. WPI will evaluate alloys that represent both good physical and mechanical properties and then develop castability indices. The melting and casting characteristics to be considered include: quantity and type of sludge produced during melting, melt fluidity, tendency of the alloy to die sticking, and tendency of the alloy to hot tearing. The comprehensive data set that will result should enable metallurgists, die casters, and design engineers to fully exploit the potential of aluminum die casting alloys.

North American Die Casting Association Rosemont, IL	*Hayes Tech Center, Ferndale, MI*	*Wabash Alloys, Wabash, IN*
Aluminum Casting Research Laboratory Consortium	*Stahl Specialty Aluminum, Kingsville, MO*	

Clean, Machinable, Thin-Walled Gray & Ductile Iron Casting Production, University of Alabama - Birmingham - The primary focus of this project will be to continue to identify and determine how the occurrence of microcarbides, silicides, and other objectionable phases can be controlled within the normal foundry process (rather than by heat treatment). Alloy combinations will be explored that will maintain strength while improving machinability. Machining operations will be extended from drilling to include turning, and data will be obtained with higher performance tools including carbides and ceramics. In addition, properties will be measured on selected classes of irons to provide data for linear elastic stress codes that can be used to design castings for reduced mass.

Cummins Engine, Columbus IN	*Daimler Chrysler, Indianapolis IN*	*Mercury Marine, Fond du Lac, WI*
ABI, Oakland CA	*Wells Manufacturing, Woodstock IL*	*Seele Corp, Hendersonville NC*
Consolidated Diesel, Whitakers NC	*Ford Motor Co, Dearborn MI*	*Technalysis, Indianapolis IN*
Bosch Breaking Systems, South Bend IN	*Hiler Industries, LaPorte IN*	*Waupaca Foundry Co., Waupaca WI*
Caterpillar Inc., Peoria IL	*Ingersoll Cutting Tools, Rockford IL*	*Wheland Foundry Co., Chattanooga TN*
Copeland Corporation, Sidney OH	*Kohler, Kohler WI*	

Creep Resistant Zinc Alloy Development, International Lead Zinc Research Organization - This project will develop zinc-based die casting alloys suitable for processing by the hot chamber die casting process that have improved creep strength. Many applications such as fasteners in automobile underhood applications require zinc alloys to maintain a minimum load under long term loading.

North American Die Casting Association Rosemont, IL	*Die Makers, Monroe City, MO*	*Eastern Alloys, Maybrook, NY*

Design Parameters for Lead Free Copper Based Engineering Alloys in Permanent Molds, Materials Technology Laboratory - The objective of this research is to determine the tensile, fracture toughness, impact and fatigue properties of 12 copper-base alloys for use in more demanding engineering applications. Permanent mold casting offers improved surface finish, precise and consistent dimensional control and improved mechanical properties. Tensile, fracture toughness, slurry wear, and corrosion properties are not adequately addressed in current ASTM specification (B806-93) for permanent mold copper-based alloys. It covers six alloys in two categories: aluminum bronze and silicon brasses. Data is needed for high copper alloys, high strength yellow brass, silicon bronze, nickel silver, and high manganese brass. The composition limits for these alloys were developed for sand casting and not optimized for the faster cooling rate experience in permanent mold casting. The zinc equivalent in high strength brasses is a useful predictor for ensuring good balance between strength and ductility in particular applications. Corrosion studies show that permanent mold samples experience general surface corrosion whereas sand-cast samples have localized corrosion. Fracture and impact properties are strongly influenced by composition with most alloys exhibiting relatively high values and these values correlate with high tensile elongation.

American Foundry Society, Des Plaines, IL	*Bunting Bearing Corp., Perrysburg, OH*	*Starline Manufacturing Co, Inc., Milwaukee, WI*
AB Chance Co., Centralia, MO	*H. Kramer & Co., Chicago, IL*	

Development of a Fatigue Properties Data Base for Use in Modern Design Methods, Climax Research Services - The objective of this project is to develop a comprehensive database of strain-life fatigue data for graphitic cast irons. Specifically, the structural grades of gray iron, ductile iron, austempered ductile iron and compacted graphitic iron will be included. Each grade will be evaluated with microstructures corresponding to two cast section sizes for comparison, thus resulting in two materials to be described per grade of iron. The database of cast iron fatigue properties will be suitable for modern design techniques. This will enable designers to use modern durability modeling to develop more precise and efficient cast iron components. Cast iron producers will benefit by expanded markets while end-users will see cost savings in component development.

American Foundry Society, Des Plaines, IL	*Bay Engineered Castings Inc., De Pere, WI*	*TRW Automotive, Livonia, MI*
Applied Process, Livona, MI	*Caterpillar, Inc., Peoria, IL*	*Waupaca Foundry Inc., Waupaca, WI*
Arvin Meritor Automotive, Troy, MI	*Citation Corporation, Birmingham, AL*	*Wheland Foundry, Chattanooga, TN*

Effects of Externally Solidified Product on Wave Celerity and Quality of Die Cast Products, Ohio State University - The heat and mass transport phenomena which occur in the shot sleeves of cold chamber die casting systems have significant effects on the reproducibility of the die casting process and resulting die cast components. The goal of this project is to increase productivity and improve the quality of die castings. It will improve the industry understanding of the alloy solidification which occurs in the shot sleeve and its effects on the filling of both the shot sleeve and die cavity during the injection portion of die casting.

North American Die Casting Association Rosemont, IL

Heick Die Casting Corp., Chicago, IL

Walkington Engineering, Cottage Grove, WI

Briggs & Stratton Corp., Milwaukee, WI

Enhancements in Magnesium Die Casting Die Life and Impact Properties, Case Western Reserve University - The objective of this project is to improve the toughness of cast magnesium alloy products and evaluate the effect these alloys have on the thermal fatigue life of steel dies used in die casting them. Jointly, these improvements are expected to accelerate the penetration of magnesium components into the automotive and commercial markets. The specific areas that will be examined in this study are the alloy selection, the processing conditions, and the life of the dies and tools that are employed to make these die castings.

North American Die Casting Association Rosemont, IL

A. Finkle & Sons Co., Chicago, IL

Chrysler Corporation, Auburn Hills, MI

CMM Services, Morton, IL

Crucible Steel, Syracuse, NY

DCD Technologies, Cleveland, OH

Ford Motor Company, Dearborn, MI

FPM Heat Treating, Chicago, IL

General Die Casters, Akron, OH

General Motors, Bedford, IN

Mercury Marine, Solon, OH

Partnership for a New Generation of Vehicles

UBE Machinery, Ann Arbor, MI

Grain Refinement of Permanent Mold Cast Copper Base Alloys, Copper Development Association - Grain refinement is a well-established process for many cast alloys, especially aluminum, resulting in enhanced casting characteristics and improved mechanical properties. Grain refinement of copper-base alloys in permanent mold casting process is fairly new and is aimed at improving the hot tearing resistance. Yet, there is a lack of understanding of the interaction between the grain refiner and minor elements present in copper alloys, such as Sn, Al, Bi, Se, and Pb. The evaluation of nuclei formation which causes the grain refinement in copper alloys is also necessary. The Copper Development Association and industry partners will conduct a series of research tasks to understand grain refinement behavior of permanent mold copper-base alloys. This will increase casting fluidity, reduce hot tearing, and increase pressure tightness. This will in turn result in higher casting yield in foundries. The project will greatly improve the ability to produce components for plumbing and other applications while responding to environmental issues surrounding lead in plumbing components and foundry sand.

American Foundry Society, Des Plaines, IL

Kohler Company, Kohler, WI

Starline Mfg. Co., Inc., Milwaukee, WI

Hubbel Power Systems, Centralia, MO

Sloan Valve Company, Augusta, AR

H. Kramer & Co., Chicago, IL

PIAD Precision Casting Corporation, Greensburg, PA

L. Fazekas Patterns & Models, Inc., Brantford, Ontario

IMA USA, Inc., Sheboygan, WI

The Brost Foundry Company, Cleveland, OH

R. Lavin & Sons, Inc., Chicago, IL

International Copper Association, New York, NY

Brass and Bronze Ingot Manufacturers, Chicago, IL

Kirit Dave (Consultant), Naperville, IL

Heat Treatment Procedure Qualification for Steel Castings. Pennsylvania State University - Currently, specifications for steel castings do not address the necessary heat treatment procedure control to assure casting performance. This is true for high alloy steel castings where proper heat treatment is the key to obtaining corrosion performance and for carbon and low-alloy steels where proper heat treatment is the key to obtaining mechanical performance. This project will identify simple but robust "heat treatment qualification procedures" that can be performed by foundries to demonstrate and assure casting performance. Heat treatment procedure qualification strategies will be developed for carbon steels, low alloy steels, and high alloy steels. It is expected that the heat treatment qualification concepts developed can also be applied to other heat treatment casting alloy families.

American Steel Foundries, Granite City, IL

Frogswitch, Carlisle, PA

The Harrison Steel Castings, Attica, IN

Milwaukee Steel, Milwaukee, WI

Missouri Steel Castings, Joplin, MO

Pacific Steel Castings Company, Berkeley, CA

Pennsylvania Foundry, Hamburg, PA

Sawbrook Steel Castings, Lockland, OH

Stainless Foundry & Engineering, Milwaukee, WI

Varicast, Vancouver, WA

West Michigan Steel Foundry, Muskegon, MI

Mechanical Properties Structure Correlation for Commercial Specification of Cast Particulate Metal Matrix Composites, University of Wisconsin - Milwaukee - The objective of this research project is to evaluate mechanical testing and structural characterization procedures for commercially available particulate metal matrix composites, in particular for aluminum alloy - silicon carbide particle composites. This study will provide quantitative comparative data generated cooperatively by material suppliers, casting producers, and casting users, including the United States Automotive Materials Partnership, to help establish industry procedures for mechanical testing and structural characterization. It will generate "Metals Handbook" grade data on mechanical properties and examine variations in properties with different material suppliers, foundries and testing agencies.

American Foundry Society, Des Plaines, IL
Alcan, Pittsburgh, PA
Caterpillar, Peoria, IL
Chrysler Corporation, Indianapolis, IN
Eck Industries, Maybrook, WI
Ford Motor Company, Dearborn, MI
General Motors, Bedford, MI
Kennametal, Latrobe, PA
Lanxide, Newark, DE
Norton, Worcester, MA
Waupaca, Waupaca, WA

Metallic Reinforcement of Direct Squeeze Die Cast Aluminum Alloys for Improved Strength and Fracture Resistance, Case Western Reserve University - The goal of this project is to develop feasible methods of reinforcing aluminum die casting components with large size metallic inserts that will provide greater strength, improved impact resistance, and reduced tendency to shatter. Activities include: reinforced casting experiments; bonding technique; mechanical testing; and in-plant implementation.

North American Die Casting Association Rosemont, IL
Black and Decker, Baltimore, MD
Briggs Die Casting, Wauwatosa, WI
Cummins Engine, Columbus, IN
Kowalski Heat Treating, Cleveland, OH
Lester Precision Die Casting, Twinsburg, OH
Los Alamos National Laboratory, Los Alamos, NM
ZMD Mold and Die, Mentor, OH
Zoller, Ann Arbor, MI

Predicting Pattern Tooling and Casting Dimensions for Investment Casting, Oak Ridge National Laboratory - This project will develop tools for predicting pattern tooling and casting dimensions for investment castings. It accounts for the thermal expansion of wax, wax mold, shell mold, and alloy materials, as well as the solidification characteristics of the casting in the shell mold, taking into account solidification shrinkage, plastic yield, creep, elastic contraction, and mold restraint. A number of findings have been made: relevant properties of shell materials include both thermophysical and mechanical properties; dimensional changes of the shell mold are affected by the thermal expansion characteristics of the shell; prefiring temperatures and holding times affect thermal expansion/contraction properties of shells; and a key point in thermal expansion characteristics is the Sinter Start temperature.

American Foundry Society, Des Plaines, IL
Howmedica, Inc., Rutherford, NJ
Howmet Corp., Whitehall, MI
MINCO, Inc., Midway, TN
PED Manufacturing Ltd., Oregon City, OR
Precision Metalsmiths, Inc., Cleveland, OH
Spokane Industries, Spokane, WA

Prevention of Porosity in Iron Castings, Climax Research Services - The goal of this project is to develop a model to help foundries learn the mechanisms of porosity formation and other effects of gases in their iron castings. It will establish a quantitative relationship among the factors affecting porosity formation and better enable foundry operator to reduce/eliminate porosity formation in a production environment. For most foundries, porosity problems occur sporadically, but even occasional outbreaks can be costly. Even a small amount of porosity can significantly reduce the mechanical properties of the castings; as a result, the casting will have to be scrapped. In general, ½ to ¾ of the all-scrap castings are lost to factors related, directly or indirectly, to porosity. It is essential for the foundries to learn the mechanisms of porosity formation and other effects of gases in their iron castings. It is also essential to establish a quantitative relationship among the factors affecting porosity formation, in a form that can be used to predict its formation in a production environment.

American Foundry Society, Des Plaines, IL
Albany Research Center, Albany, OR
Borden Chemicals, Toledo, OH
Briggs & Stratton Corporation, West Allis, WI
Citation, Birmingham, AL
Columbia Steel Castings, Portland, OR
Durametal, Muncy, PA
Georgia Iron Works, Grovetown, GA
Hickman Williams, Livonia, MI
Intermet, Lynchburg, VA
Maca Supply, Springville, UT
Q.I.T. America, Chicago, IL
Texaloy Foundry, Floresville, TX
United Foundries, Canton, OH
United Machine & Foundry, Winona, MN
Wagner Castings Company, Decatur, IL
Waupaca Foundry, Inc., Waupaca, WI

Semi-solid Metals, Oak Ridge National Laboratory - This project will address fundamental technical issues of semisolid metal (SSM) processing, improve process control and material characterization, and contribute to the development of a knowledge base for the commercial sector. In the SSM process, the raw material is melted and allowed to cool and solidify, while the dendrites formed during solidification are broken up and their morphology is altered using mechanical, electromagnetic or other forces. Subsequently, the specially prepared raw material is remelted to its mushy state, and, while the temperature is kept between the liquidus and solidus isotherms, it is processed to its final shape. The flow of these rheologically complex fluids in shape making operations in a rapid cycle mode is highly unsteady, which significantly influences the overall quality of the final product. To better understand the process and to optimize the operation, it is important to gain a deeper insight into the theoretical and physical concepts associated with this family of thixotropic materials and for a material characterization of SSM processed materials.

North American Die Casting Association Rosemont, IL

Alcan International Limited, Montreal

Aluminum Company of America, Alcoa Technical Center, PA

Aluminum Pechiney, Paris, France

Kaiser Aluminum and Chemical Corporation, Spokane, WA

Northwest Aluminum Company, The Dalles, OR

Ormet Corporation, Wheeling, WV

VAW, Inc., Pittsburgh, PA

Wabash Alloys, Wabash, IN

Buhler, Inc., Minneapolis, MN

Chem-Trend, Inc., Howell, MI

Foseco, Inc., Bessemer, AL

Heraeus Electro-Nite Company, Philadelphia, PA

Metallurg Aluminum, Newfield, NJ

Briggs & Stratton Corporation, West Allis, MI

Daimler Chrysler Corporation, Indianapolis, IN

Ford Motor Company, Dearborn, MI

General Motors Corporation, Pontiac, MI

Harley-Davidson Motor Company, Milwaukee, WI

Mercury Marine, Fond Du Lac, WI

A-Mold, Mason, OH

AEMP Corporation, Jackson, TN

Amcast Industrial Corporation, Southfield, MI

Cambridge Tool and Manufacturing Company, Inc., North Billerica, MA

Citation Corporation, Birmingham, AL

Consolidated Metco, Clackamas, OR

Selee Corporation, Hendersonville, NC

Thixomat, Ann Arbor, MI

J.L. French International, Sheboygan, WI

Kennedy Die Castings, Inc., Worcester, MA

Madison-Kipp Corporation, Madison, WI

Palmer Foundry, Inc., Palmer, MA

SPX Contech Division, Portage, MI

Stahl Specialty Company, Kingsville, MO

Superior Industries International, Inc., Morris, MN

Teksid Aluminum Foundry, Inc., Dickson, TN

Wyman Gordan Investment Castings, North Grafton, MA

Hayes Lemmerz International, Inc., Ferndale, MI

Hitchcock Industries, Inc., Minneapolis, MN

Intermet Corporation, Lynchburg, VA

Prince Machine, Holland, MI

Systematic Microstructural Corrosion Performance Evaluation of CN3NM and CK3MCuN High Molybdenum Stainless Steel, University of Tennessee - This research will systematically document the microstructural phase evolution in two types of high molybdenum stainless steel castings as a function of solution heat treatment parameters, and then relate the microstructure to corrosion performance.

Steel Founders' Society of America Barrington, IL

Atlas Foundry and Machine, Tacoma, WA

Esab Welding & Cutting Products, Hanover, PA

Keokuk Steel Casting, Keokuk, IA

Quaker Alloy, Inc., Myerstown, PA

Welding Research Council, New York, NY

Wollaston Alloys, Inc., Braintree, MA

Products & Markets

Qualitative Reasoning for Additional Die Casting Design Applications, Ohio State University - This project builds off a previous effort, Simple Visualization Tools, to improve die design. It's goal is to develop design tools for die casting that can promote compatibility between the design and the die casting. Activities include: extending the fill analysis to include lower velocity flow present in low pressure die casting, squeeze casting and gravity casting; thermal/temperature extensions to provide a relative, equilibrium temperature distribution in the part and die; and qualitative shrinkage/distortion predictions for the part.

North American Die Casting Association, Rosemont, IL

EXCO Engineering, New Market, Ontario

Ford Motor Company, Dearborn, MI

General Motors Powertrain, Pontiac, MI

ITT Industries, Auburn Hills, MI

J.L. French Corporation, Sheboygan, WI

Ryobi Die Casting, Inc., Shelbyville, IN

Spartan Light Metal Products, Sparta, IL

Tool Products, Minneapolis, MN

Walkington Engineering, Cottage Grove, WI

Thin Section Steel Castings, Pennsylvania State University - Continued customer demand for lighter casting weights point to significant market opportunities for high strength, thin-wall steel castings in automotive applications and thinner wall castings for a wide variety of other applications. Further replacement of traditional steel component designs with lighter weight cast iron or cast aluminum components can be expected unless thinner section steel casting capabilities can be developed. Although the development of the FM Process by Pont-a-Mousson in France in the mid 1980s and the development of the Hitchiner Process in the U.S. in the 1990s have been driven by wall thickness reduction, the capabilities of conventional, low cost sand casting processes of making thin wall steel castings has not been fully explored. Research carried out at the Pennsylvania State University is to develop a fundamental understanding of the key technologies needed to develop lighter weight, thinner section steel castings. The focus is toward an understanding of technologies and practices that will enhance mold \cavity filling. The necessary thin section practices will be identified and/or developed from mold making to melting and pouring. As a result of this cooperative industry/university research program, a comprehensive science and practice-based understanding of thinner wall steel casting will be demonstrated. A three year multi disciplinary effort will be directed by a task group of the Steel Founder's Society of America Carbon and Low Alloy Research Committee as well as by the participating foundries. A comprehensive thin section steel casting technology monograph will be developed to aid foundries in the implementation of the technologies developed.

Steel Founders' Society of America Barrington, IL

Pelton Casteel, Milwaukee, WI

Spokane Industries, Spokane, WA

Durametal Corp., Muncy, PA

Pennsylvania Steel, Hamburg, PA

Varicast, Inc., Portland, OR

Pacific Steel Casting Co., Berkeley, CA

Quaker Alloy, Myerstown, PA

Environmental Technologies

Development of Technical Data to Validate the Performance of Foundry Byproducts in Hot-mix Asphalt and Controlled Low-strength Material, Pennsylvania State University - The goal of this project is to develop technical data to validate performance characteristics of foundry byproducts in hot-mix asphalt and controlled low-strength material. The data will be made publicly available and enable the construction industry to evaluate and use foundry sand as an aggregate for various materials. It is estimated that approximately 8 million tons of foundry sands and slags could be available for reuse every year. Most spent foundry sands and slags have characteristics that allow for reuse as fine and coarse aggregates in a number of engineered applications. However, the engineering specifications and technical performance standards for reuse of foundry sands and slags have not been developed. Additionally, the environmental characteristics of foundry byproducts in reuse applications are not universally understood. Compiling this information is prohibitively expensive for most small foundries. Together, these technical barriers constitute major impediments to foundry byproduct reuse activities.

University of Wisconsin, Madison, WI

Illinois Cast Metals Association, North Pekin, IL

Pennsylvania Foundrymen's Association, Plymouth Meeting, PA

American Foundry Society, Des Plaines, IL

Indiana Cast Metals Association, Indianapolis, IN

Process Recovery Corp., Sinking Spring, PA

Badger Mining Corporation, Berlin, WI

Kurtz Brothers, Inc., Groveport, OH

U.S. Environmental Protection Agency, Chicago, IL

EOAssociates, Mill River, MA

Ohio Cast Metals Association, Columbus, OH

Wisconsin Cast Metals Association, Milwaukee, WI

Foundry Association of Michigan, Lansing, MI

Payne & Dolan, Inc., Waukesha, WI

GM Environmental Services Division, Detroit, MI

Energy Consumption of Die Casting Operations, Ohio State University - The objective of the project is to examine energy consumption as a cost of die cast products. The use of life cycle assessment (LCA) to compare the environmental impacts of materials and energy inputs and waste outputs for various components for automotive, appliances, and electronic products is an emerging trend. Several companies are participating in this study and will supply information on energy and equipment. The U.S. die casting industry needs to characterize their energy usage to identify opportunities for energy savings and to compare usage with other industries. To facilitate implementation of energy audits by die casters who will help identify energy drivers, additional templates are needed to disaggregate a facility's energy use and allocate it to specific activities. A pre-survey and focus energy audit standard will be completed. The survey will examine the die casting industry to determine current energy management practices and adapt a Griffith's energy audit standard to focus on characterization of energy use by die casting activity. Statistical analysis will be used to examine U.S. die casting industry usage data by contrasting the data by categories for equipment age, type, fuel source, insulation, and coverage, process configuration, and alloys. The energy use will be compared between the data accumulated against reported energy use in other sectors. Recommendations will be developed for energy conservation and energy management practices that may provide cost savings for the die casting industry.

North American Die Casting Association Rosemont, IL

GM Powertrain, Bedford, IN

Premier Tool & Die Cast Corporation, Berrien Springs, MI

Ergonomic Improvements for Foundries, Iowa State University - Manual operations remain an important part of many metal casting operations, due to the diverse products produced. This diversity makes automation infeasible. This project will take a reactive and proactive approach to solving ergonomic problems which lead to poor product quality, poor productivity, and poor lead times. The purpose of this project is to introduce ergonomic thinking into the foundry industry. It will involve student training, mini-workshops and evaluations, and off-site assessments of process evaluations. Process improvements and ergonomic improvements will be identified. The project team will work with participants through training and workshops to introduce improvements on to the foundry floor.

Steel Founders' Society of America Barrington, IL

AECCO, Champaign, IL

Atchison Casting, Atchison, KS

American Steel Foundries, East Chicago, IL

Bay Cast, Inc., Bay City, MI

Buckeye Steel Castings, Columbus, OH

Carondelet Corporation, Pevely, MO

Durametal Corporation, Muncy, PA

Erie Bronze & Aluminum, Erie, PA

Falk Corporation, Milwaukee, WI

Harrison Steel Castings, Attica, IN

Hendrix Manufacturing, Mansfield, LA

Magotteaux Pulaski, Pulaski, TN

Maynard Steel Casting Co., Milwaukee, WI

McConway & Torley Corporation, Pittsburgh, PA

Monett Metals, Monett, MO

NACO, Lombard, IL

Pacific Steel Casting, Berkeley, CA

Pennsylvania Foundry Group, Myerstown, PA

PrimeCast, South Beloit, IL

Sawbrook Steel Castings Co., Lockland, OH

Sivyer Steel Corporation, Bettendorf, IA

Southern Alloy Corp., Sylacauga, AL

Southern Cast Products, Meridian, MS

Southwest Steel Castings Co., Longview, TX

Spokane Steel Foundry Co., Spokane, WA

Sulzer Pumps, Easley, SC

Texas Steel Company, Fort Worth, TX

United Machine and Foundry, Winona, MN

Varicast, Inc., Portland, OR

Waukesha, Delavan, WI

West Michigan Steel Foundry, Muskegon, MI

Wisconsin Centrifugal, Waukesha, WI

Wollaston Alloys, Braintree, MA

Non-incineration Treatment to Reduce Benzene and V.O.C. Emissions from Green Sand Molding Systems, Pennsylvania State University - Green sand foundries are under increasing pressure to reduce benzene and volatile organic carbon (VOC) emissions during pouring, cooling and shakeout. Conventional incineration systems to treat stack gases are expensive to operate and difficult to maintain. Alternative pollution prevention strategies must be developed to comply with ever more demanding air quality requirements. Full-scale plant trials at green sand foundries have shown that simple non-incineration Sonoperoxone™ (SP) treatment systems or a combination of Sonoperoxone™ Plasma (SPP) treatment can significantly reduce emissions. This project is developing a fundamental understanding of SP and SPP processing. Plant trials and laboratory tests will be conducted to further optimize systems that have been already installed at production foundries. Performance characteristics and effectiveness of non-incineration treatments to reduce benzene and VOC emissions for green sand foundries will be demonstrated.

American Foundry Society, Des Plaines, IL

Furness-Newburge, Inc., Versailles, KY

Grede Foundries, Inc., Reedsburg, WI

International Truck and Engine Corp., Waukesha, WI

Neenah Foundry Company, Neenah, WI

Wheeland Foundry, Chattanooga, TN

Steel Foundry Refractory Lining Optimization: Electric Arc Furnace, University of Missouri - Rolla - Researchers at UMR have been working with the wrought steel industry to better understand the mechanisms, which govern the wear of furnace refractories. Many new refractory materials have been developed during that same period and have been used successfully by wrought steel producers. But, largely because of elevated costs, these materials have not found widespread usage in steel foundries. In the current project, the researchers at UMR will build on the experience they gained with wrought steel production to assist steel foundries. The main focus of the project is to optimize the refractory systems used in electric arc furnaces (EAFs) in the steel foundries. This will be accomplished by determining the best combinations of refractory materials, slag compositions, and melting practice to increase the refractory life in EAFs.

Steel Founders' Society of America, Barrington, IL

ABC Rail Products, Anderson, IN

ABC Rail Products, Calera, AL

American Cast Iron Pipe Co. Birmingham, AL

Atchison Casting, Atchison, KS

Baker, Refractories, York, PA

Electroalloys Corp., Elyria, OH

The Falk Corporation, Milwaukee, WI

GH Hensley Industries, Dallas, TX

Harrison Steel Castings, Attica, IN

Keokuk Steel Castings, Keokuk, IA

Missouri Steel Castings, Joplin, MO

North American Refractories, State College, PA

Pelton Casteel, Milwaukee, WI

Quaker Alloy, Inc., Myerstown, PA

Varicast, Inc., Portland, OR

Wahl Refractories, Fremont, OH

Wellsville Fire Brick Co., Wellsville, MO